PELICAN BOOKS

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A GUIDE TO EARTH HISTORY

RICHARD CARRINGTON

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BY

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For Panther

WHO SHARED THE EXCITEMENT

AND THE WORK

On the ship Earth which bears us through immensity towards an end that is only known to God, we are steerage passengers – emigrants who know only their own misfortune. The least ignorant amongst us, the most bold, ask themselves questions; they ask when the voyage of humanity began, and how much longer it will last; what drives the ship onward, why the hull and decks vibrate, and why at times sounds rise from the depths below and go out by the hatchways; they ask what secrets are concealed in the bowels of the mysterious ship, and are unhappy that they do not know the answer. Others, the great majority of the passengers, content themselves with mere existence, looking forward each day to a tomorrow that they hope will be better.

You and I belong to the restless and daring company who wish for knowledge and are never satisfied with any reply. These stand together on the prow of the ship, watchful for every sign that comes from the mysterious interior, or from the monotonous sea, or the still more monotonous sky. They comfort one another by speaking of the shore to which they earnestly believe they sail, where they will surely arrive one day, where even tomorrow, perhaps, they may come to anchor. Not one of them has seen this shore, but all would recognize it without a moment's doubt were it to appear on the horizon. For it is the shore of the land of their dreams, 'where the air is so pure that there is no death', the land that they yearn for with all their hearts – and its name is Truth.

PIERRE TERMIER: *La Dérive des Continents*, 1924

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PREFACE

THIS book is an attempt to answer in simple, non-technical language some of the questions asked by reflective people concerning the history of the Earth and the way its life has evolved. To compress the story of 3,000 million years into less than 300 pages is an ambitious and perhaps foolhardy task. My excuse for attempting it is that the subject, although of absorbing interest, is little known outside specialist circles, and that much of the material concerning it is only otherwise available in text-books and somewhat formidable technical monographs.

As presented in these pages the story of our Earth's past must necessarily be briefly told and cannot hope to be adequate to the grandeur of its theme. I have nevertheless done all that I can to make it as accurate and complete as possible within the framework of a general and popular history.

The period covered is from the origin of the Earth itself until the dawn of the characteristically human phenomenon known as civilization, which completes the history of man as an animal. I have added in the last chapter a purely personal view of the place that science, art, and religion may occupy in the history of the Earth and of life, and of the opportunities and dangers that I believe may confront mankind at the present time. This is almost the only occasion on which I have forsaken the record of fact, and allowed myself an expression of opinion.

Although I have tried to produce a narrative requiring no previous knowledge of any branch of science, I have not insulted the reader by turning the correct scientific Greek and Latin names of the animals of the past into inadequate English. Some of these are admittedly difficult, but they have a romance of their own, and should be easily mastered by reference to a good scientific dictionary.

It would be impossible to acknowledge individually my debt to all the authorities in geology, palaeontology, geophysics, astronomy, anthropology, and other branches of science whose original researches have contributed so much to our knowledge of Earth history and whose brains, as expressed in their writings, I have picked without scruple. A list of the most important sources of my facts will be found in the bibliography on page 257.

I would, however, like to express my sincerest personal gratitude to those authorities who have been kind enough to read the whole or part of the manuscript and to make many constructive criticisms and suggestions. These include, Dr A. T. Hopwood, Dr W. E. Swinton, Dr Errol I. White, and Dr Maurice Burton of the British Museum (Natural History); Professor F. E. Zeuner and Dr Ian Cornwall of the Institute of Archaeology, London University; Dr W. C. Osman Hill of the Zoological Society of London; and my friend, Dr Edward Hindle, F.R.S. If the book has any merit at all it is largely due to help from these sources; its inadequacies are entirely my own.

My thanks are also due to Mr G. B. Stratton of the library of the Zoological Society of London; Mr H. B. Rowbotham of the Geological Library, British Museum (Natural History); the library staffs of the Royal Anthropological Institute, the Institute of Archaeology, and the British Museum, Bloomsbury; and especially to Mr Maurice Wilson, whose magnificent illustrations will be regarded by many people as the book's most attractive feature.

In conclusion, may I hope that this history, with all its shortcomings, will do something to satisfy the curiosity and stimulate the imagination concerning the past of the Earth and the mysterious evolution of life that has taken place upon its surface. Earth history, like astronomy and philosophy, is a subject that helps to bring the anxieties and petty conflicts of everyday life into proper perspective. I feel that this fact alone makes its study worth while.

R. C.

PART ONE

Prologue: The Earth

CHAPTER I

THE EARTH IN SPACE

THERE is no more awe-inspiring spectacle than the night sky, and nothing more chastening to human vanity than the Earth's apparent insignificance in the unbounded wastes of space. Contemplation of these things poses so many questions that it is not surprising that the Earth's place in the Universe, and its relation to the other celestial bodies, are problems with which every age has been preoccupied. They are an essential background to the Earth's own story and to the way that life has developed.

For primitive man even more than for ourselves the Earth and sky inspired emotions of reverence and terror. His viewpoint was different from ours, however, for he had not yet progressed very far in scientific knowledge and his emotions were rooted in magic and superstition. Also the true structure of things was hidden from him and he relied mainly on the direct evidence of his senses. For example, he believed that the Earth was a flat plain, moulded in places into hills and valleys, while the sky was a finite, domed ceiling, mysteriously illuminated by night with tiny globes of fire. His view was more personal than ours. He was interested in the forces of nature as magical or practical aids rather than from any desire to understand the laws that governed them. His world was, in fact, entirely centred on himself, and nature was good or bad according to her efficiency in providing for his everyday human needs.

The first theories of the Universe reflected primitive man's subjective attitude. The Earth, it was thought, being the nearest and most familiar object of experience, must be the centre of things, and sun and moon, planets and stars, must revolve around it. This was a theory that could be substantiated by common sense, for even the most superficial observation of the sky would show that sun and moon and planets moved in orderly progression from horizon to horizon.

This view persisted until quite late in human history. Its most famous expression was known as the Ptolemaic System evolved by the Alexandrian astronomer Claudius Ptolemy in the second century A.D. This was based on the early assumptions of Greek and Egyptian science and was accepted in human thought for nearly 2,000 years. The Earth, said Ptolemy, lay at the centre of the Universe, and was encircled by a series of crystal spheres, regularly spaced and each supporting a planet. The sun, which was also regarded as a planet, lay on the fourth sphere from the Earth, while the eighth and outermost sphere, known as the Starry Sphere, carried all the fixed stars. The spheres revolved at different speeds, and were reputed to give off sounds corresponding to their velocities, which blended together to form a heavenly harmony.

It is agreeable to contemplate our Earth in this privileged position, its inhabitants listening enraptured to the strains of a cosmic orchestra. But unfortunately modern science has revealed a more austere prospect. Beginning with Copernicus in the fifteenth century, new speculations were made concerning the Earth and its relation to the outer Universe, and the old theories were gradually overthrown. Today the crystalline spheres with their heavenly harmonies seem like a fairy tale dream; in their place, astronomy, the most majestic of the sciences, has revealed to us a Universe in which our Earth plays the humblest and most insignificant of roles – a Universe where all human experience can be measured by a single tick of the cosmic clock and life itself may prove to be only a casual incident.

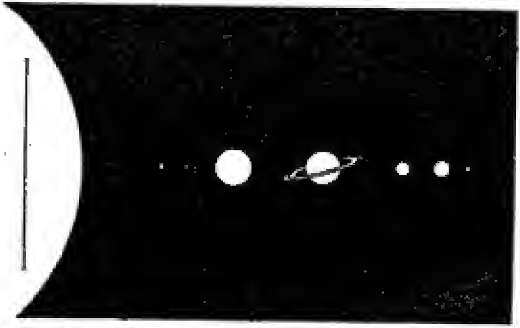
What, then, is the picture that modern science has built up for us of the Earth and its position in space? And how can we learn from it a new perspective on Earth history, and the drama of our planet's evolving life? These are questions that must be answered before we can tell the Earth's own story.

The Earth, as everyone knows, is one of the nine planets that circle round the sun. The sun is the source not only of life, but possibly even of the Earth itself. It is one of the so-called 'fixed' stars, measuring 854,000 miles across with a surface temperature of 6,000° C. Inside it is considerably hotter, estimates of its temperature varying from 20 million to 40 million degrees centrigade. This is at least 6,000 times hotter than the most efficient electric furnace that man has yet devised.

The sun's age must be reckoned in thousands of millions of years, so evidently its heat does not come from ordinary combustion. Even considering its size, which is over 1¼ million times that of the Earth, there is no combustible material that could have been burnt at such a rate for more than a few thousand years without being expended. The explanation of this immense source of energy is to be found in nuclear transformation. It is the conversion of hydrogen into helium in the sun's interior that unleashes the energy to warm our Earth and maintain the complex patterns of life.

The planets spin round the sun in nearly circular concentric orbits, the nearest, Mercury, at a distance of 36 million miles, the farthest, Pluto, at 3,669 million miles. Our own Earth is one of the nearer planets, being distant only about 93 million miles. To complete its orbit in a single year it has to travel at a speed of more than 70,000 m.p.h.

The origin and nature of the planets will be discussed more fully in the next chapter, but before moving out from the Solar System its size may perhaps be made more comprehensible by an illustration. Let us suppose that the sun were reduced to a sphere four and a half feet across and that we began to walk away from it in a straight line in search of the planets; at what distances would we come across their orbits? Well, we should walk over fifty yards before we reached a planet at all, and then it would be only the diminutive Mercury, no larger by our scale than a very small pea. Next would come Venus, and then Earth (161 yards), which would be the largest planet so far – roughly the size of a half-inch marble. Beyond Earth the distances between successive planets would increase greatly so that with two exceptions each would be approximately double the last. First, 244 yards from the sun, would be Mars, and then, at 836 yards, the giant Jupiter, the largest



Planets of the Solar System represented on the same scale as the sun. Left to right: Arc of the sun, Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, Pluto (distances not to scale; the black line on the sun's surface represents the sun's radius)

of the planets, a gaseous globe nearly six inches across. On the final stage of our journey we should pass Saturn (1,533 yards), Uranus (3,084 yards), and Neptune (4,833 yards), to arrive finally at Pluto at a distance of over three and a half miles.

As these figures indicate, one of the most striking characteristics of the Solar System is the small size of the sun and planets compared to the distances which separate them. This principle applies even more forcibly to outer space. Concentrations of matter in the form of stars and planets are infinitely rarer in the Universe than would be half a dozen golf balls scattered at random in the Sahara desert. This intense loneliness of the Earth, and the immensity of astronomical distances, can best be appreciated by a glance beyond the Solar System to the vast star city that contains it.

The system of stars to which the Solar System belongs is known as the Galaxy. It is shaped rather like a giant cart-wheel with a thick hub, the stars being scattered at random through it, and the Solar System occupying a position near the rim. When you look at the Milky Way you are in fact looking along the 'spokes' of the wheel and viewing the Galaxy from the inside. This is why the stars of the Milky Way seem to be so closely packed: they are being seen one behind the other, as it were, so that they naturally appear more congested than the stars lying out at right angles to the 'wheel'.

The size of this vast Galaxy of stars defies any imaginative effort to comprehend it. Light, travelling at 186,000 miles per second, takes between 60,000 and 100,000 years to cross from one rim to the other; even to span the thickness of the wheel at the axle several thousands of such 'light years' are required. There are about 10,000 million stars in the Galaxy, many undoubtedly with a retinue of planets, and even the nearest star to Earth, known as *Proxima Centauri*, is so remote that its light takes over three years to reach us.

As if these figures were not staggering enough, the great astronomical telescopes have given us during the last half century an even more awe-inspiring view. They have shown that beyond the Galaxy, and at an immense distance from it, the recesses of space are dotted with island universes every bit as complex as our own. These remote agglomerations of stars are known to astronomers as the extra-galactic nebulae, and the latest telescopes suggest the existence of over 100 million of them. They are scattered through space in every direction at fairly regular intervals, the distance between each nebula and its neighbour being somewhere in the region of 1½ million light years.

To get an idea of this arrangement of the outer Universe, it may help if we imagine each nebula as a thick disc with a diameter of between two and four inches. We should then picture to ourselves a vast globe measuring two miles across, inside which these disc-like nebulae are miraculously suspended, our own Galaxy in the centre. The discs would be scattered through the globe in every direction, vertically and horizontally, each being at an average distance of three yards from its neighbours. The surface of the globe would of course be an artificial boundary representing the maximum range of existing telescopes in our own Galaxy, and there would be no reason to suppose that the arrangement did not continue indefinitely. Substituting for each disc the huge bulk of a nebula, we may perhaps obtain some slight idea of the prospect revealed by the latest telescopes at Palomar and Mount Wilson Observatories.

And now, after this digression into outer space, we must literally come back to Earth. What have we learnt by the voyage and how may it affect our vision of Earth history?

The first consequence of any meditation on the facts of astronomy must be a feeling of the deepest humility. Against the vast backcloth of the Universe we find that many of the basic assumptions of ordinary life are called in question, and even the subtler revelations of art and religion take on a new perspective. In history especially we must ascribe new meanings to the words 'progress' and 'evolution', for our ultimate destiny can no longer be defined.

On an Earth contained by the harmonious spheres against a background of tinsel stars it was perhaps not difficult to find comfort in magic, or dogma, or faith. Much was inexplicable, doubtless, in that wondrous progress from the darkness of creation to man's ultimate home in a gilded heaven, but the Way was laid down and the destiny of the individual and the race was not seriously in doubt. The new cosmology has shattered this vision. Account must now be taken of the new scales of distance and of time, and especially of those recently discovered worlds in the depths of space where other forms of life may exist, following a different pattern from ours and evolving to different ends.

The following pages, which deal with the origin of the Earth and the way its life has developed, are intended to be read with these possibilities in mind. There is no immutable law to say that scenes which have been enacted on a puff of stardust in a moment of time should have any ultimate significance. But only by knowing what they have been, and feeling the wonder of them with sufficient intensity, can we hope to understand the workings of the Universe around us and have a glimpse of its meaning.

CHAPTER 2

THE ORIGIN OF THE EARTH

MAN has speculated on the origin of the Earth from the beginning of recorded history. Arguments concerning the method of creation occur in every religion, from the most primitive to the most advanced, and have given rise to many picturesque tales. For example, in the Babylonian creation we hear how the great god Bel Marduk fought the female dragon Tiamat, rent her in two, and set up one half of her body to form the sky and the other to form the Earth. More poetically the *Taittirīya Brāhmana*, one of the sacred books of India, tells how the Creator, Prajapati, dived for the Earth into the universal waters of the Beginning: coming up with a handful of soil he spread it on a lotus leaf that grew from the waters and fastened it down with pebbles.

This conception of a liquid origin of the Earth is common in most ancient mythologies. The Egyptians believed that the elements of Earth were evolved in the primal chaos of the universal ocean, called Nu. A similar conception is found in Hebrew writings where the primeval sea is called 'tehom'; it was believed that the word of God caused tehom to be divided in two, the upper waters being shut up in heaven while the lower ones cradled the Earth. Similar ideas are found today in different parts of the world. In one Polynesian myth, for example, it is told how the god Tangora fished up the world from the ocean; but unfortunately his line broke and it slid once more beneath the waves, leaving behind only those fragments known as the South Sea Islands.

But the most picturesque of all legends of the Earth's origin is that of the cosmic egg. Here it is in the simple language of the *Chhāndogya Upanishad* of India, which tells how Earth grew from meditation on Brahma, the timeless essence of the Universe: 'In the beginning this was non-existent. It became existent, it grew. It turned into an egg. The egg lay for the time of a year. The egg broke open. The two halves were one of silver, the other of gold. The silver one became this Earth, the golden one the sky, the thick membrane (of the white) the mountains, the thin membrane (of the yolk) the mist with the clouds, the small veins the river, the fluid the sea.' This story of the origin of the Earth in the cosmic egg is found throughout the whole of Eastern philosophy and religion.

Men's conceptions of the form of the Earth were as bizarre as their theories of its origin. To some, as we have already said, it was a flat plain with a dome of stars; to others it was a box-shaped mass floating on a limitless sea. Even the Roman Pliny, who had read Greek authorities for the world's spherical shape, could not quite understand why people at the antipodes did not fall off.

Such fanciful conceptions persisted in different forms until the sixteenth century. Even after that, scientists and other honest observers were derided and sometimes persecuted for daring to question the authority of tradition. We can understand, perhaps, why Copernicus's great *De Revolutionibus Orbium Coelestium* was banned by the Holy Congregation of the Index in 1616 because its author had asserted that the Earth travelled round the sun. What today seems almost incredible is that as recently as a hundred years ago the vast majority of Europeans believed that the Earth had been created in six days.

Confronted by such a tangled web of poetry and prejudice science was not able at first to make much headway. Even today no sure answer can be given to the problem of the Earth's origin, and many time-honoured theories are rapidly being superseded. For example, it is now by no means certain that the Earth and the other planets originated in matter torn from the sun. It is at least equally likely that they once formed part of an unknown star now swimming remotely in outer space.

The first theory of the Earth's origin that could be dignified by the description scientific was that proposed by the German philosopher Immanuel Kant and elaborated by the French mathematician and astronomer Pierre Simon, Marquis de Laplace. Laplace, who was born in humble circumstances, the son of a peasant farmer in Normandy, was one of those astonishing men of genius whose ideas were destined to change the whole course of human knowledge. His 'nebular hypothesis' for the origin of the Solar System was first published in 1796 as the seventh supplementary note to his *Exposition du Système du Monde*; it has since had to be abandoned, but is worth describing as the first serious attempt to elucidate the problem and as a stimulating influence that has led to many later theories.

The Solar System, according to Laplace, may have begun as the result of an internal explosion in the sun, which dispersed its atmosphere into a huge ball of superheated gas extending far beyond the orbits of our present planets. The force of the sun's rotation was transferred to this attenuated ball of gas so that it gradually assumed the shape of a disc, or nebula, turning with a regular but fairly slow motion in the same direction as the present planets' courses. Gradually heat was dissipated from this disc by radiation into interstellar space, and as it cooled it began to shrink. Now it is a well-established scientific law that as the size of a rotating body gets less, so its speed of rotation increases. But as the speed of rotation increases so does the force, known as centrifugal force, which tends to make the object disintegrate. There comes a moment when this centrifugal force equals, and then exceeds, the gravitational force which tends to hold the body together. This is what Laplace assumed to have happened in the case of the sun, the result being that the outermost edge of the nebula, being no longer under the sun's gravitational pull, was left as a gigantic ring in space. Other smaller rings were left until the sun had contracted to its present size. Laplace maintained that it was the condensation of these rings into spheres of gas that led to the creation of the planets.

It was an attractive theory, but unfortunately for Laplace it was open to several criticisms. Most of these are too technical to be gone into here, but what they really amounted to was that matter simply does not behave in this way.

There is no known physical or mechanical law which would explain the formation of gaseous rings of the type that Laplace described. Even less plausible was the suggestion that they could have actually condensed into planets.

Much more popular and long-lived than the Laplace nebula hypothesis have been the hypotheses of solar disruption. There have been several of these, but they all start from the same basic idea. Briefly and simply put, this is that the surface of the sun was disrupted by the impact or near approach of another star, and that the Earth and the other planets were produced from the matter which escaped from the sun's surface at that time. As this theory has played an extremely important part in scientific thought we must examine it a little more closely.

The first man to speculate along these lines was, surprisingly enough, not primarily a physicist or an astronomer but a naturalist. He was a contemporary of Laplace's and his name was Georges Louis Leclerc, Comte de Buffon, whose monumental *Histoire Naturelle* we shall have several occasions to refer to in the chapters that follow. For our present purpose what concerns us is his statement, made in one of the volumes of this book, that the planetary system originated in a catastrophic collision between the sun and some body from outer space. Buffon called this other body a comet, a fact which has led to the disregard of his theory, for the material of comets is now known to be insufficiently concentrated to produce anything like the required impact. But this is simply a confusion in terminology, for Buffon knew very well the physical requirements of such a body if it was to produce the effect he described. The main value of Buffon's contribution was that it established in scientific thought the possibility, even the probability, that the planets were forcibly torn from the sun by some sort of cosmic accident.

Theories based on this assumption have found considerable favour. The first was the so-called 'planetesimal hypothesis' put forward early this century by two American scientists, T. C. Chamberlin, a geologist, and F. R. Moulton, an astronomer. This theory did not suggest that an actual collision had occurred between the sun and some other body; it assumed only the near approach to the sun of a second star. The gravitational pull of this star set up great tidal bulges of gas on opposite sides of the sun's surface. As the star reached its nearest point these bulges became so great that explosive forces within the sun began to eject masses of sun material from them in the form of 'bolts'. Eventually these bolts cooled to form a vast mass of small solid bodies called 'planetesimals', which circled the sun under the influence of its gravitational pull. Next the larger planetesimals attracted the smaller ones to them, and in this way the planets were built up by a process of accretion, not, as is more usually assumed, by cooling and shrinking from a molten state.

The theory aroused great interest, but as with its predecessors reasons were brought forward to show why it could not be true. The objections were mainly based on the theory's assumption that the planets had always been solid bodies. It was pointed out that some of the planets were still very largely composed of gas, a fact that was difficult to explain away if they were solid originally.

In an attempt to meet these criticisms the most recent of the solar disruption hypotheses was put forward in the late nineteen twenties by the great British astronomer, Sir James Jeans. Working with the geophysicist, Harold Jeffreys, he reached the conclusion that the planets were originally gaseous and had been drawn from the sun's surface entirely through the gravitational pull of the second star, unaided by explosive forces in the sun itself. The approach of this star, he asserted, had produced waves on the sun's surface which had eventually grown so big that they had parted company with the sun altogether and streamed out into space in the form of a thin gaseous filament. The instability of this thin stream of gas had caused it to break up into several parts which had slowly cooled and condensed to form the planets.

This theory of Jeans's has held the field for over a quarter of a century, but during the last four or five years it has been assailed by the entirely revolutionary view that the Earth and the other planets were not produced from the sun at all. An example of this new approach is the theory of atomic disruption of an unknown star put forward by the two Cambridge scientists, R. A. Lyttleton and Fred Hoyle.

Lyttleton and Hoyle began by amplifying a criticism of the Jeans theory, first made by H. N. Russell, which said that if the theory were right the planets would have to be circling the sun at a very much closer distance than they actually are. On top of this criticism came the discovery that planetary material contains elements of a very different kind from those normally found in the sun. In other words the sun would be a most unlikely source for the kind of materials which compose the Earth as we know it.

The alternative theory put forward by Lyttleton and Hoyle is briefly as follows. The sun, they say, may once have formed part of what is known as a double star, or 'binary system'. Half the stars in the sky conform to this pattern; that is to say, although they appear because of their remoteness to be single stars they are in reality pairs of stars revolving round each other like two dancers in a ballroom performing an endless series of natural turns. According to the theory the sun's companion star in this binary system was of a type called by astronomers a *supernova*. Supernovae are stars which, for reasons we need not go into here, tend to disintegrate with extreme violence due to atomic explosions in their interior. When this happens a huge cloud of brightly incandescent gas is projected outwards at several millions of miles an hour and the star nucleus that is left behind recoils like a cosmic cannon ball fired into the depths of space. But the gases of the explosion remain, and if, as Lyttleton and Hoyle assumed, these were 'captured' gravitationally by the companion star – in this case the sun – they would have formed a gaseous ring out of which the planets could have condensed.

This, then, is one of the latest theories to account for the Earth's origin, but the problem is still far from being solved.

All that can safely be said is that the Earth and the other planets were probably born at the same time; that the Earth has almost certainly passed through a gaseous stage, and that its present appearance is due to the transformations it has undergone during a long period of contraction; and that, so far as we can tell, it is the only planet in the Solar System that can support life as we know it. With these factors in mind we can now ask what science has to tell us about the nature of the Earth itself and the way in which it has evolved.

CHAPTER 3

THE ARCHITECTURE OF THE EARTH

WHAT do we know of the structure and proportions of the Earth on which we live? And what are the means by which this knowledge is obtained? These are the questions that we must now answer.

The study of the Earth as a physical entity is known as geophysics, a science that deals in its broadest application with every aspect of the Earth from its centre to a point many miles above its surface. Geophysics is divided into four main departments. The first of these studies the interior of the earth, or 'centrosphere' as it is technically called, trying to deduce the nature of those mysterious regions that must be forever hidden from the eyes of men. The second deals with the Earth's surface, or 'lithosphere', telling us the nature of rocks and how valleys and mountains were formed. The third is concerned with the waters that lie on the surface of the Earth, known technically as the 'hydrosphere'. And the fourth deals with the Earth's outer covering of gas, or 'atmosphere', which has enabled life to develop and increase. For most of this book we shall be concerned with the second of these departments of geophysics, the department studied by the science of geology; and we shall be particularly interested in the findings of historical geology which considers the Earth's surface as the theatre of evolving life. But to obtain a proper perspective a glance must first be taken at the whole picture.

Simply defined, the Earth is a nearly spherical mass of solid and viscous material measuring 7,900 miles in diameter. It is not a perfect sphere for it is slightly flattened at the poles, a fact which accounts for the degree of latitude being longer in high latitudes than in low ones. Its surface is sculpted into hills and valleys, and more broadly divided into great continental masses and deep ocean basins. Its interior, as will appear later, is usually considered to be exceedingly hot, while the density of the Earth materials increases as one moves from the surface inwards towards the core. The volume of this enormous orange-shaped sphere is approximately 260,000 million cubic miles.

The way such a complex structure may have evolved from a mass of whirling stardust, and particularly the growth of its surface rocks, will be considered in more detail in the next chapter. Here, first of all, we are going to review our knowledge of the Earth's interior and see what sort of picture we can build up of that strange, uncharted country. This picture is essential if we are to understand the forces operating at the surface.

In recent years a great deal of speculation has been going on concerning the nature of the materials lying beneath the Earth's crust. The researches of R. M. Lees, P. W. Bridgman, and others have revealed a multitude of new possibilities which may bring about a complete revolution in our way of thinking on this subject. For instance, it has recently been suggested that the core of the Earth may consist of highly compressed hydrogen, and that instead of cooling down it may be gradually heating up. These ideas at the moment are too controversial and contradictory to have found a generally accepted place in scientific thought, and for this reason they will not be specially emphasized in this and the following chapters. But it should be remembered that the whole of the traditional concept of the Earth's architecture and evolution is now under fire, and that no definite conclusions are therefore possible. With this proviso in mind let us see what kind of approach science has already made to the many problems involved.

The deepest mine in the world, the Robinson Deep in South Africa, is less than 10,000 feet below ground, an infinitesimal fraction of the total diameter of the Earth. It is obvious, therefore, that any direct knowledge we can have of the interior is extremely limited, and our findings must be based upon deduction. Yet even at this comparatively shallow depth we find ourselves already in possession of a significant fact: that the farther we descend into the Earth the higher the temperature becomes. This, moreover, is a characteristic of all mines all over the world, irrespective of their latitude or the temperature at the surface.

Considering the comparatively small distance involved, the increase in temperature is spectacular, being no less than 16° F. for every 1,000 feet, and sometimes even more. In fact, in the Robinson Deep, as in many other mines, an elaborate air-conditioning plant has had to be installed to prevent the miners from being roasted to death. Moreover, temperature tests taken down oil borings, which are the deepest man-made incisions in the Earth's crust, show that the heat continues to increase in proportion to the depth of penetration.

It follows that at no great distance from the Earth's crust the heat of the interior should reach 212° F., the boiling point of water. This must, in fact, be the case, as is proved by the hot springs and geysers which gush forth in widely separated parts of the world. These are caused by water percolating through cracks and fissures in the Earth to a depth where it turns to steam, whereupon it is forced up once more under its own pressure into the open. In special circumstances the source of these geysers may be only a few hundred yards below ground, but the average depth at which vaporization occurs is one and a half miles.

As with water, so with rocks and minerals. At a distance of just over thirty miles below the surface, if we assume the same regular increase of heat, the temperature reaches 2,220° F. or more, a point at which several kinds of rocks begin to melt. At 3,300° F., a few miles farther down, no known rock could normally exist in a solid state. It is the emergence of this molten rock from fissures in the Earth's crust that causes the eruption of volcanoes, and has been taken by many authorities as proving the molten nature of the Earth's interior.

The source of this heat, and the reason why it has not long ago been dissipated by radiation from the Earth's crust, has been for many years a subject of scientific argument. According to an early view expressed by the nineteenth-century physicist Lord Kelvin, the heat was produced by ordinary radiation from the sun material of which the Earth was originally composed. The Earth, in fact, was gradually becoming cooler and would end its career as a solid, cold, and lifeless planet. In recent times this view has been considerably modified. The source of heat, it is said, is the gradual breaking down of radioactive elements in and below the Earth's crust. This breaking down process is accompanied by the release of large amounts of energy which are sufficient not only to maintain the inner temperature of the Earth, but to compensate also for the radiation losses at its surface. Modern science thus offers us the possibility of a surprising conclusion, namely that we dwell on a natural atomic pile and that, far from becoming cooler, the Earth's internal temperature may actually be increasing. It must be remembered, however, that the internal temperature of the Earth has only a very slight effect on the surface temperature, which is otherwise entirely controlled by the sun's rays. The temperature of the Earth's core has been variously estimated at 3,000°-6,000° C. or even more, yet the heat reaching the surface from below the crust is about 30 million times less than the heat it receives from the sun.

Having established the size and shape of the Earth, and made a guess at its internal temperature, science's next problem must be to deduce the nature of its materials. Except for the rocks of the Earth's crust, which are readily accessible, we may well wonder how we can give an account of materials that can never be directly examined. The problem is indeed a difficult one and many conflicting views have been expressed. Here we shall restrict ourselves to describing a few of the lines of attack that have been most commonly used.

The first of these is the study of meteorites, which from time to time penetrate the Earth's atmosphere and come to rest upon its surface. Meteorites are solidified particles from other celestial bodies, and have generally been regarded as samples of the materials to be found within our own Earth. They vary greatly in size, the smallest being no larger than pebbles, while the largest may weigh between 100,000 and 200,000 pounds. The world's largest meteorite crater, near Winslow, Arizona, measures over 1,300 yards across and must have been created by a meteorite, now deeply embedded in the Earth, weighing several millions of tons. The most common materials in all the meteorites so far examined have proved to be metallic iron and stone.

Another important source of information concerning the Earth's interior is the behaviour of earthquake waves. Earthquakes are the result of large-scale movements beneath the Earth's crust leading to a rearrangement of the surface rocks. The cause of these Earth movements is still uncertain, but their disastrous consequences to human beings are only too familiar. Earthquakes have their uses however – at least to the scientist – for the waves which radiate from each centre of disturbance can be recorded by the delicate instruments known as seismographs, and used as pointers to the kind of materials of which the centrosphere is composed. Three types of waves are recognized, passing respectively through the Earth's deepest layers, the less deep layers, and the upper crust. As it is known that all the waves in any particular shock originated in the same place and at the same time, we have only to record their times of arrival at any given seismological station to be able to work out their relative speeds. Attempts have been made to deduce from these the general nature of the rocks and minerals through which they have passed.

What picture can we build up of the structure of our Earth from these and the other means of knowledge at our disposal? It seems probable in the first place that the Earth consists of a series of concentric zones varying greatly in complexity. Beginning from the surface, there is first a succession of rocks, known as sedimentary rocks, which are actually visible to human eyes in quarries and mines and on mountain sides. These sedimentary rocks are not regularly laid down one above the other like the layers of a cake, but for reasons that will appear later, are often worn away, twisted and jumbled up, as if they had been battered by some cosmic giant. Below the sedimentary rocks is a foundation of what are known as igneous rocks, from the Latin *ignis*, meaning fire. These rocks differ from the sedimentary rocks in that they have not been laid down through the action of wind and weather, but have been formed directly from a molten state by cooling. The most common example of this type of rock is the familiar granite found on Dartmoor and in the English Lake District.

The solid sedimentary and igneous rocks form the main body of the Earth's crust, and their combined materials make up a zone roughly forty miles deep. Although this sounds a remarkable thickness it must be remembered that in relation to the Earth's total diameter it is as thin as the skin of an apple. According to the traditional view this crust is supported by a band of rock known as basalt, which extends for a further thirty-five miles into the Earth's interior. Beyond this lies the great peridotite layer over 700 miles thick, possibly composed of the mineral olivine in a highly plastic state. Next, between the peridotite layer and the core, comes the thousand miles of the transition zone, whose constitution has always been highly speculative. Finally comes the core itself, more than 4,000 miles across and consisting, according to the traditional theory, of iron or nickel iron in a plastic condition.

The interacting forces of temperature and pressure at the heart of the Earth are on a fantastic scale. We have already spoken of the possibility that the Earth's core is at a temperature of 6,000° C. – an estimate which some authorities consider conservative. The pressures are equally enormous. It is estimated that less than half way to the Earth's centre the pressure of the overlying materials exceeds 20 million pounds per square inch: at the centre this is more than doubled, being somewhere in the region of 20,000 tons. The great heat, tending to increase the volume of the molten Earth materials and make them less dense, is counteracted by the almost inconceivable pressure which tends to squeeze them into a smaller and more solid shape. A constant war is therefore being waged between the forces producing liquid and solid states, with the result that the Earth's interior may preserve some of the characteristics of both.

Finally, in this brief survey of the architecture of the Earth, we must say a word or two about its atmosphere. This extends upwards into space in all directions for a distance of several hundred miles, but after fifty miles it is already becoming extremely attenuated. At the Earth's surface the atmosphere consists principally of two gases, oxygen and nitrogen, the latter being nearly four times more common than the former. There are also small quantities of carbon dioxide and water vapour, and some chemically inert gases. As the air becomes more rarified with height, the amounts of the various gases in a given volume of air naturally decrease; hence the great difficulty of supporting life at the top of high mountains without an artificial supply of oxygen.

Although it is not obviously perceptible to us, the atmosphere has weight. The pressing down of the upper layers on the lower produces a pressure at sea-level of fourteen and a half pounds per square inch. We do not notice this pressure for it is applied equally to every part of our bodies, and they are sufficiently rigid to stand up to it without discomfort. But it is physically very apparent in aeroplanes and rapidly moving lifts when our ears begin to hurt owing to unequal pressure behind and in front of the drum. In extreme cases such variations in atmospheric pressure can lead to nose bleeding, or even to bursting of the ear drums.

In the form of the air we breathe the atmosphere is one of the basic necessities of life, but even in a less fundamental sense it has a great influence on our everyday activities. It is the source of our climate and our weather; it is the medium through which our aeroplanes fly; and until recently it provided (in the form of winds, which are simply atmosphere in motion) the motive power for most of our ships and mills. Even in the aesthetic field its influence is felt, for it forms an essential part of the pageant of dawn and sunset and the sombre magnificence of stormy skies.

The atmosphere concludes this part of our enquiry into the nature of the Earth. It brings us also to a good moment for recapitulating the discoveries we have made so far. We began with a picture of our Earth, infinitely lonely, swimming through the vastness of space, as insignificant as a cork in the middle of the Pacific Ocean. We looked at some of the theories put forward for the origin of this tiny planet, and saw how the whole of our history and present existence has probably stemmed from an immense cosmic catastrophe. Finally we have inspected our modern Earth at closer range, glancing briefly at its surface structure, dwelling in more detail on the mysterious nature of its interior, and concluding with a few facts about its atmosphere. But there remain what are probably the two most fascinating problems of all – the problems of time and of growth. How long ago was our Earth created, and through what long ages did it slowly evolve? If it is true that it originated in incandescent stardust, how did this turn to the complicated formations of its geological crust? How long was it lifeless, and how did life eventually develop to its present complexity? These are the kind of questions that we must now attempt to answer.

CHAPTER 4

THE AGE AND EVOLUTION OF THE EARTH

According to the seventeenth-century Irish Archbishop James Usher, the Earth was created on Saturday, October 22nd, 4004 B.C., at 8 o'clock in the evening. This startling pronouncement, with its pleasing exactitude, was made in a book called *The Annals of the World* published in London in the year 1658. Usher had worked out his figures by much complicated addition and subtraction of dates from the different chronologies of the Old Testament, and had the satisfaction of seeing them inserted by some over-zealous editor as a marginal note in the King James version of the Bible. This led to their becoming accepted as a part of religious dogma, and for more than a century it was heresy to believe that the Earth, with all its complex features, had taken longer than 6,000 years to evolve.

The first scientist to throw an intellectual grenade into this comfortable and orderly scheme was the French naturalist Buffon, whom we have already met as the author of an early theory of the Earth's origin. In 1778, in his *Époques de la Nature*, Buffon proposed a new scale of time for Earth history. He was wise enough not to give definite dates, but divided the Earth's past into seven epochs. In the first epoch, for which he allowed about 3,000 years, the Earth cooled from an incandescent to a molten state. The next 35,000 years or so constituted an epoch of gradual consolidation in which the crust began to take on its present form. In the third epoch, lasting from 15,000 to 20,000 years, the water vapour in the atmosphere began to fall as rain, covering the Earth with a universal sea; at this time also the first life began to appear in the waters, and stratified rocks began to form from marine sediments. The fourth epoch of 5,000 years saw the retreat of the waters and the beginning of a period of intense volcanic activity. Finally three epochs saw the appearance of the more advanced forms of life, culminating in man, whose supremacy, it was assumed, would last until the Earth cooled and life became extinct.

During the nineteenth century a long and bitter war was waged between religious orthodoxy and the more scientifically minded who, following Buffon, demanded an ever-increasing allotment of time to account for the development of the Earth's major physical features. The orthodox thinkers put up a good fight, but the pressure of accumulating facts proved too much for them. The paltry allowance of 6,000 years for the Earth's creation and growth was extended first to 100,000 years, then to 400 million. Finally even the protests of the faithful were stilled by the sublimity of the new conception, and today the age of the Earth is reckoned at the altogether inconceivable figure of 3,000 million years.

What is the evidence that has driven us to accept such vast vistas of time? This question can best be answered by a more detailed consideration of the physical processes that have formed the Earth's crust.

Working on the assumption that our Earth originated as a spinning globe of incandescent gas, let us try to picture what happened when it began to cool. The first transformation was from the completely gaseous to the completely molten. From this point, as we have already suggested, it seems likely that the radioactive materials within the Earth maintained its internal temperature at a roughly constant level, or even, perhaps, increased it. This was not, however, true of its surface, which when it was still in molten form was undoubtedly losing vast amounts of heat by radiation, resulting in a quick fall in temperature. Eventually the surface temperature must have dropped to the point where the surface materials began to solidify and the molten sphere acquired a solid crust.

The first effect of this was to arrest at the underside of the crust the convective currents in the molten material of the interior, which had formerly radiated their heat directly into surrounding space. These currents, incidentally, played a great part in determining the inner constitution of the Earth, for they transported the lighter materials, such as granite and basalt, to the surface, while the heavier iron and iron-nickel sank to the centre. With the solidification of a rocky crust the cooling of the Earth was considerably retarded. Instead of being carried all the way to the surface by convection, the heat at the last stage had to be slowly conducted through a rocky shell.

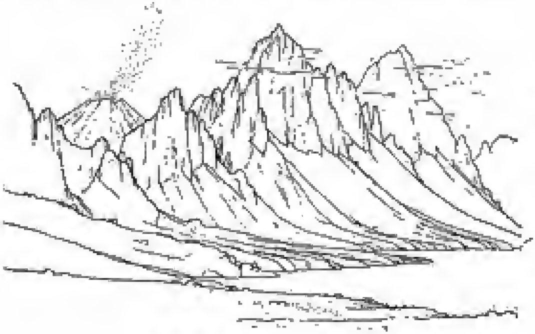
The tendency henceforward was therefore for a balance to be struck between surface radiation and the generation of atomic heat in the interior. Until this occurred the crust gradually cooled, thickening as it did so, until a thermal equilibrium was achieved which has probably varied little throughout the Earth's history. But the technicalities of this process are of less interest to our purpose than the probable aspect of the surface at that time.

The first rocks to solidify were the so-called 'igneous' rocks, which we defined, it will be remembered, as those which had been formed directly from a molten state by cooling. These began to make a crust on the Earth, as cream collects on top of a churn or as the outer surface of a molten metal ball is the first part to solidify in a foundry. In the earliest stages, of course, they were intensely hot, radiating a fierce white heat. The Earth at this time must have looked like a gigantic fiery furnace, the semi-molten rocks seething and bubbling, and assuming a variety of fantastic shapes as they gradually hardened into a rigid skin.

At that time the Earth had no atmosphere as we know it. The rocks were far too hot to permit the condensation of water vapour, or even the formation of clouds. The air was filled with the acrid fumes thrown off by the newly formed rocks, and the heat within hundreds of miles of the Earth's surface was of unimaginable fierceness and strength.

But gradually, through many thousands of years, the Earth cooled. The rocky surface, reinforced from within by solidifying basalt, grew thicker. Clouds began to form, at first in wisps and patches, and then in great massed banks that for long ages obscured the face of the sun, covering the Earth in a sombre and impenetrable shroud.

At long last, as the cooling process continued, rain began to fall. At first it came in droplets which were instantly vaporized as they touched the scorching rocks beneath. But gradually the surface temperature dropped lower and lower until it was below the boiling point of water; and then the rain began to run over the black rocks in hot rivulets and to collect in the shallow depressions to form the first lakes and pools. Never since has the Earth seen such rain as fell in those first centuries of its history: it came down from the



The barren Earth before life appeared

cloud banks in a merciless deluge, as if it would go on for all eternity.

But at length a time came when the clouds began to disperse, for the Earth's surface was attaining a more moderate temperature and the cycle of evaporation and condensation was beginning to slow up. The steaming lava fields slowly cooled and the tepid streams combined into mighty rivers which fed the first seas. The internal heat of the Earth ceased to affect in any large degree the temperature of the surface: instead the sun's rays, combined with the Earth's Topography, began to produce local climates, and with them all the familiar and contrasting features of our everyday weather. For the first time in the Earth's history there began to operate the complex forces which regulate heat and cold, and determine the incidence of drought and tempest and flood.

It may now be asked how our present-day Earth has been built up, and why modern geologists have allowed for the process such an immense period of time. The evidence lies in the rocks of the Earth's crust. It has already been said that in addition to the igneous rocks there are a large number of sedimentary rocks, and that although these appear to have been originally deposited in layers they are now twisted and broken as if by the hand of a cosmic giant. These rock layers were in fact laid down by the very weathering forces we have just described. Wind, water, and ice, constantly assaulting the surface of the igneous rocks, carried away particles of their surface, and bore them suspended in river water to the sea. Here they were spread out in deltas and on the floor of the ocean basins in the form of beds of sediment which gradually solidified into new rocks. Further layers were laid down on top of these and were affected by heat and pressure in different ways so that numerous distinct formations grew up. It has been estimated that if all these sedimentary rock strata since the beginning of time had been allowed to accumulate one on top of the other they would now have reached a thickness of at least ninety-five miles.

The reason that this has not occurred is that the Earth is conventionally believed to be a shrinking body. Loss of heat has led to contraction of the molten core, and the effect of this has been to set up immense lateral strains in the crust. The surface rocks have been impacted into one another, and the complicated interplay of tensions has led to the creation of mountain ranges and gigantic rift valleys.

The circumference of the Earth is now actually believed to be about ninety-four miles shorter than it was at the time the crust was formed, and its surface area to have been reduced by over 1½ million square miles. The result of this has been to force upwards above the surface of the Earth more than 23 million cubic miles of solid rock. A large proportion of this rock must have been of the sedimental type, which was subjected in its turn to the same erosive forces that had attacked the basal igneous rocks. The effect of this was to wear away completely some of the layers, while others were so altered and distorted by the pressure of the shrinking Earth as to become unrecognizable. At the same time, to add to the confusion, volcanoes and other subterranean forces were injecting new layers of molten igneous rocks between and above the sedimentary rocks, so that the rock record became distorted in the extreme.

With this picture in our minds we can now return to the question of the Earth's age. Even to the early nineteenth-century scientists it was apparent that the forces behind such vast geological changes must have taken an immense span of time to operate. Anyone who has been on a hillside during a shower of rain will have had a convincing demonstration of this fact. A raindrop falls on the soil, and a minute particle of earth is washed perhaps a quarter of an inch downhill. The process is repeated on that particular particle probably only two or three times in each shower. Yet these are the forces that through the long aeons of geological time have washed away mountains higher than the Andes or the Himalayas, not once, but time and time again – as often, in fact, as new ranges have been upraised by the pressure of the shrinking Earth.

The realization of the way these forces worked was first made by a Scottish doctor named James Hutton. On March 7th, 1785, he read a paper to the Royal Society of Edinburgh which was to change the whole course of geological history. It was called *The Theory of the Earth*, and it set forth Hutton's belief that the forces of wind and weather now in operation would have been capable, *if given sufficient time*, of producing every existing feature of the Earth's crust. He was driven to the conclusion that the Biblical creation was a figment of men's imaginations, concluding his essay thus: 'It is vain to look for anything higher in the origin of the Earth. . . . We find no vestige of a beginning, – no prospect of an end.'

The events of the next fifty years proved that, despite widespread opposition, Hutton's theory was undeniably true. It became known as the doctrine of 'the uniformity of nature', or 'uniformitarianism', and was fully developed in the nineteenth century by the British geologist Sir Charles Lyell. Lyell's three-volume *Principles of Geology*, published between 1830 and 1833, became, in fact, the bible of the new science.

The scale of time having been so greatly extended, the next problem was to date the past of the Earth. The rate at which sediments accumulate in river valleys was quickly seen to be one method of doing this. Thus in 1852 excavations at Memphis in Egypt exposed the foundations of a gigantic statue of Rameses II buried under nine feet of sediment. The age of the statue was known to be about 3,200 years, and it was therefore a simple matter to deduce the rate at which the deposits had been laid down. In this way a rough yardstick was created which enabled age to be correlated with depth; for example, when, a few years later, some burnt brick was discovered at a depth of forty feet in the same layer, its age could be estimated with reasonable certainty at about 13,500 years.

Although this method is still satisfactory for dating the comparatively recent past, it is quite inadequate for dealing with the long ages of geological time. The rate of deposition varies with the relief of the land and the fluctuations of climate, so for the remote past a more accurate method is required. One such method is derived from the rate at which the sea is becoming salt. Laymen are often surprised to learn that this saltiness is not a constant factor but increases steadily with time. The salt in the sea, it is now realized, comes from the sediments brought down by the great rivers. The insoluble particles are deposited on the sea floor in ever-growing layers, but many of the salts remain in solution. When the sun evaporates water from the sea surface, these salts are left behind. The evaporated fresh water falls again on the land in the form of rain and brings down further salt and sediments, so that the salinity of the sea is continually being increased.

It seems obvious that by estimating the amount of salt held in solution by the world's oceans and dividing it by the annual rate of deposition by the world's rivers, we should arrive at a figure for the age of the Earth. This has been done, and the resulting figure comes out at about 100 million years. Unfortunately, however, this estimate is inaccurate, and a moment's thought will show us why. Firstly, and most obviously, the salt-impregnated layers of sediment at the bottom of the sea have many times in the Earth's history been squeezed and folded upwards to form dry land, as has already been described. This dry land is then eroded all over again, but being itself of undersea origin, the new salts it produces only serve to falsify the calculation. Also the height of the lands bordering the oceans determines the rate of deposition, and this height has not remained constant throughout geological time. In short there are too many imponderables in this method to make it more than a very rough guide.

Fortunately, however, there is now one way of dating the Earth's past that can claim to be entirely practical and accurate. This is based on the properties of the radioactive materials which are known to form part of the Earth's crust. These make an extremely valuable geological clock by which scientists can tell to within a few million years how old a particular rock formation must be.

We have already told how the radioactive elements in the rocks are gradually breaking down and giving off the heat that maintains the Earth's internal temperature. The main agencies of this kind are the elements uranium and thorium, and as these change their state by radioactivity they become in succession a number of different elements. Finally they become stable, and this end product is found, surprisingly enough, to be ordinary lead.

Fortunately the rate of radioactive decay is found to remain constant under the widest range of temperature and pressure. To determine the age of a rock, therefore, all that is necessary is to measure its lead content and compare it with the known rate of radioactive change. The most ancient rocks so far measured by this method have proved to be the coarsely crystalline igneous rocks known as pegmatites from Rice Lake, Manitoba, whose age has been estimated at about 2,100 million years. This confirms that the age of the Earth itself must be somewhere in the region of 3,000 million years.

With this figure known, the problem of Earth chronology becomes principally one of dividing its history into the main geological periods. These are not arbitrarily laid down, but mark definite events in the Earth's evolution. They are milestones fixed by dramatic transformations of the Earth's crust, often involving sweeping changes in climate, vegetation, and animal life. But before explaining them, we must first introduce those silent witnesses of the past who play such an all-important part in our story – the fossils that lie buried in the rocks of the Earth's surface.

CHAPTER 5

WITNESSES OF THE PAST

FOSSILS are the remains of dead animals and plants preserved in the Earth's crust, and the study of fossils forms a large part of the science of palaeontology, a name that comes from three Greek words meaning 'the science of ancient being'. One of the valuable functions of palaeontology is to act as a kind of connecting link between the sciences of geology and biology, for it draws part of its information from both. In his search for fossil remains the palaeontologist must be well versed in geological techniques; he must know where to look for his specimens, and how to extract them from the rock when he has found them. But he must also know a great deal about many branches of biology, especially comparative anatomy, or he will be unable to interpret his finds or fill in the inevitable gaps in his record.

By the aid of fossils palaeontologists can now give us an excellent picture of the life of past ages. The palaeontologist is really a 'time detective', whose clues are footprints and fragments of bone – sometimes also the remains or imprints of skin and flesh. From these he reconstructs for us not only the murderous crimes of the past – although these were frequent enough – but also the appearance and habits of the many extraordinary creatures who preceded us in the domination of the Earth.

Not all remains of dead animals are regarded as fossils; to qualify for the name they must have been in existence for some considerable time. Nor are fossils necessarily the remains of extinct animals; the bones of animals recently extinct, unless of great age, are not regarded as fossils, while ancient remains of individuals of living species are. Antiquity is the sole factor determining what is a fossil and what is not, but it is always difficult to know where to draw the line. For this reason palaeontologists are sometimes heard to remark:

'If the remains stink, give them to the zoologists; if not, they're ours.'

The word fossil comes from the Latin verb *fodĕre*, meaning 'to dig up', and was originally given to literally anything that was dug up out of the Earth. For example Conrad Gesner, the great sixteenth-century Swiss naturalist, regarded such objects as crystals and ancient stone axe-heads as fossils, despite the fact that they were of mineral origin. Gradually, however, the term became restricted entirely to organic remains, or the impressions of organic objects, and this is the only sense in which it is now used.

Fossils may be found almost anywhere, but only very rarely in igneous rocks. This is because if an animal were ever unfortunate enough to be engulfed by a molten lava flow the heat almost inevitably destroyed its remains. Sometimes, however, a natural mould of the victim was preserved in volcanic materials. One of the most remarkable instances of this was found recently in Oregon, where an ancient rhinoceros had been overwhelmed by a lava flow. A few charred bones were all that was left of the animal itself, but a cavity exactly reproducing its shape was left in the solidified rock.

The main sources of fossils are the layers of sedimentary rocks laid down over the igneous rocks by the action of wind and water. They are particularly common in limestones and calcareous shales, but less so in such rocks as red sandstones whose chemical constitution is harmful to organic remains. A dramatic picture can be built up in the imagination of how these fossilized remains came to be buried in the rocks many millions of years ago. A dead sea creature, perhaps, once sank slowly to the ocean bed, there to be covered by an ever-thickening film of sand. The soft parts would decay, but the hard skeleton would in some cases be preserved. Or maybe a giant dinosaur, mortally sick or wounded, would fall at last in the shallow water of a river delta. When death had claimed it, and the scavengers and maggots had done their work, its heavy skeleton would slowly sink in the soft mud to be covered in a shroud of river-borne sediments. Then, many millions of years later, the slow contraction of the Earth might lift this particular bed of hardened sediment, inch by inch, century after century, until it formed the slope of some great mountain range. Ice and rain would resume their attack, and gradually the skeleton would be weathered out to the surface, to be discovered perhaps 100 million years later by some excited palaeontologist.

Such processes have gone on from the beginning of time, and fossilized remains have been found in every period of human history. In the early days of scientific knowledge naturalists were often hard put to it to explain what fossils were and many quaint theories were propounded. Aristotle, for example, in the fourth century B.C., believed that they were spontaneously generated in the rocks by some mysterious plastic force whose workings he was unable to explain. He devotes much space to them in his *Historia Animalium*, treating them as a distinct form of life, albeit of a somewhat inferior kind of natural born animals. His famous pupil, Theophrastus, modified this view. He agreed with Aristotle that fossils were of organic origin, but believed that they had grown from eggs or seeds scattered in the rocks. One of the few Greeks to have guessed the true nature of fossils was the historian Herodotus. He observed marine fossils in the desert during his travels in Egypt and Libya about 450 B.C., concluding, quite correctly, that the Mediterranean had once spread southward over North Africa and that the fossils had been left behind when it retreated.

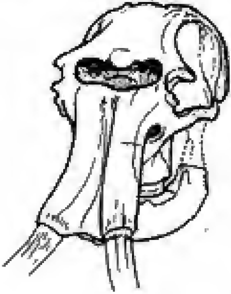
Roman science did little or nothing to modify the earlier theories of the Greeks, and in the Dark Ages, after the fall of the Empire, the whole subject was lost in a welter of ecclesiastic theory. The medieval church encouraged the idea of a six-day creation and an age for the Earth of only a few thousand years. If fossils were mentioned at all their true nature was either unknown or tactfully ignored. Lay thinkers, if sufficiently daring, stated that they must have grown from germs dropped from the stars, or have fallen fully formed from outer space. Extremists regarded them as undoubted evidence of the ingenuity of the devil.

It was the digging of canals in Italy in the late fifteenth century that reawakened scientific interest in the matter. The excavations brought to light deposits of fossil sea shells too numerous to be ignored. These greatly intrigued the great Italian artist and scientist Leonardo da Vinci, who was among the first to assert that they were the remains of creatures that had once been alive in the areas where they were found. This view, naturally enough, was very unpopular with the clergy, but they had the ground cut from beneath their feet by the seventeenth-century Danish ecclesiastic Nicholas Steno. Steno was born a strict Lutheran, became converted to Catholicism, and was made a bishop by the Pope; unfortunately, however, he was also an eminent geologist and anatomist, and two years after his conversion came out in full support of da Vinci's theory of the origin of fossils.

The growing influence of the scientific faction eventually caused the Church to retreat to new positions. Henceforward fossils were regarded as the remains of creatures that had been drowned in the Biblical flood. The classic example of this view is contained in a Latin work published in 1726 by the German physician Johann Scheuchzer. The book was called *Homo diluvii testis*, or 'Man a witness of the Deluge', and contained a description of some skeletal remains found at Oensingen in Switzerland which Scheuchzer interpreted as men who had been drowned in the Flood. It was unfortunate, perhaps, that some years later the French naturalist Baron Cuvier re-examined these remains and found they belonged to giant salamanders of the genus *Andrias*, but it says much for his sense of humour that he immediately gave them the specific name of *Andrias scheuchzeri*.

Apart from the Flood theory, many people regarded the larger fossil skeletons as the remains of giants. To this day there is a plain in the Dauphiné in France known as *le champ des géants* because of the recovery there in the seventeenth century of the bones of prehistoric elephants.

Mammoth skulls were particularly popular with the giant-mongers for, as can be seen in the accompanying illustration, the twin nasal opening in the middle of the head could easily be interpreted as the eye socket of a Cyclops. But the most entertaining comment of all, which combines both Flood and giant theories, was that made in 1706 by Governor Dudley of Massachusetts, who had been shown what was later identified as a mastodon tooth from a peat bog near Albany, New York. After announcing that the tooth measured 5¾ in. long, and weighed 2 lb. 4 oz., he continues:



A fossil mammoth skull, showing how the legend of the Cyclops may have originated

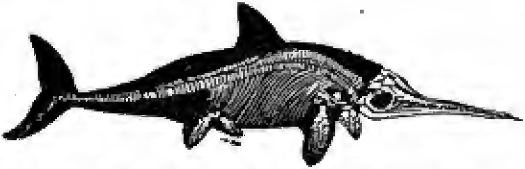
'I am perfectly of the opinion that the tooth will agree only to a human body, for whom the Flood only could prepare a funeral; and without doubt he waded as long as he could keep his head above the clouds, but must at length be confounded with all other creatures and the new sediment after the Flood gave him the depth we now find.'

Despite the pioneer palaeontological work of Cuvier and his fellow countryman, Jean Baptiste de Monet, Chevalier de Lamarck, the fossil controversy went on well into the nineteenth century. The triumph of Darwinism and the theory of evolution led to great heart-searchings among men who were both good scientists and good Christians. Sir Edmund Gosse tells how his naturalist father Philip Gosse, a strict Puritan and a Plymouth Brother, was quite unable to reconcile the two points of view. Instead he cut the Gordian knot by declaring that God must in fact have created the world, as the Scriptures said, in 4004 B.C., but that He had done so with the fossils already in place. The reception of this theory proved that even the most reactionary intellectuals regarded the six-day creation as a lost cause. We find Charles Kingsley writing to Gosse that he cannot give up 'the painful and slow conclusion of five and twenty years study of geology, and believe that God has written on the rocks one enormous and superfluous lie'. And even the high-minded Victorian press ridiculed a theory which maintained, according to the popular interpretation, that God had hidden fossils in the rocks in order to tempt geologists into infidelity.

Fossils, then, for the last fifty or sixty years, have been universally recognized for what they are. Their respectability is now accepted by the most pious, and they have become an indispensable aid to the Earth historian in his complicated task. It remains to enquire how they are preserved, and how they can be used as clues to the history of life.

The most common form of fossilization results from burial under water-borne sediments, especially at the bottom of the sea. Usually only the hard parts of the animal are preserved, but occasionally the imprint of the soft parts leaves a tracing on the rocks. For example, the muscles of a shark over 300 million years old were in one specimen so perfectly preserved that individual fibres and their cross-striations could be clearly seen under the microscope. With soft-bodied prehistoric creatures, such as jelly-fish and other invertebrates, these imprints provide our only clues to their appearance. It is unfortunate that compared to the preservation of bone structure they are always exceedingly rare.

Fossilized bones are often regarded as being literally 'turned to stone', but this is very seldom the case. Sometimes, admittedly, the bony material is replaced bit by bit by entirely different mineral substances, and can therefore be regarded as an example of true petrifaction. Far more common, however, is the process known as 'permineralization', in which the minute cavities in the buried bones become filled with particles of the surrounding mineral sediment, but without altering the nature of the original. The particles solidify, and in consequence the bone naturally feels heavier, but no chemical or mineral change has taken place in the bone itself. As the bone and its mineral filling are quite different in appearance and texture, the structure of permineralized remains can easily be studied in section under the microscope.



A fossil ichthyosaur. The black areas show where the imprint of the soft parts was left on the matrix

Mention has already been made of the natural moulds that are occasionally left in igneous rocks by animals that have been overwhelmed by lava flows. The same phenomenon can also occur in other kinds of materials. When these moulds are in a good state of preservation artificial casts can be made from them which reproduce the original shape of the remains. Sometimes Nature herself has performed this task by filling the cavity with some mineral substance. Silica or calcite especially are often found as a filling in such cavities, thereby making a natural cast.

Other interesting examples of natural moulds are those left by prehistoric insects in amber. Amber is the natural resin of ancient coniferous trees in a hardened condition. Frequently, when this resin was in its natural glutinous state, unsuspecting insects alighted on it and could not detach themselves; as the resin accumulated they gradually became permanently entombed. With the passage of time the soft parts of the insect shrivelled away, but the hard parts were preserved, and a perfect mould was left in the transparent amber. These moulds now preserve the complete shape and texture of the insect's body, so that every detail of its anatomy down to the finest hairs and wing membranes can be examined under the microscope.

But these are not the only types of fossilization. Many great animals of the past were mired in quicksands, peat bogs, or deposits of natural asphalt. At least 100 mastodon skeletons have been recovered from the peat bogs of the Big Bone Lick in Kentucky, and when Thomas Jefferson was President of the United States he devoted a special room in the White House to fossil remains from this source. Asphalt is a particularly good preservative for fossils. Bacteria cannot live in it and the effects of decomposition are therefore minimized.

Trees and plants are less often preserved as fossils than animals as they lack a bony skeleton. However, truly petrified tree trunks are by no means rare, the woody tissue being replaced by silica or calcium carbonate. The petrified forests of the United States are well known, and some examples of fossilized tree trunks can be seen not only in several British museums, but as exhibits in such homely surroundings as London's Regent's Park. Flowers, plants, and leaves are seldom completely preserved, but we can learn much about their appearance from the imprints they leave in the rocks by the process known as carbonization. As time passes, the volatile elements in plant specimens escape, but their carbon content remains, leaving an excellent carbon copy of their shape. The same process is responsible for most of the imprints of the soft parts of animals which were described above.

On very rare occasions, and under very special circumstances, the remains of a whole animal, both skeleton and soft parts, are preserved for posterity. The usual cause of this is not, strictly speaking, fossilization at all, but a process akin to deep freezing. For example, the carcases of mammoths have been found on numerous occasions frozen deeply into the Arctic tundra of Siberia and Alaska. The flesh of one such mammoth, exposed by a fall in the bank of the Berezovka River, Eastern Siberia, was so fresh that it was eaten by scavenging dogs 20,000 years after its death. In Alaska the remains of mammoth hair occur in such profusion that they have been known to interfere with the working of the gold diggings.

Caves and oil seeps are also occasional sources of completely preserved remains. There is the famous instance of a young woolly rhinoceros and a young mammoth being preserved almost whole for many thousands of years in an oil seep at Starunia, Galicia. The skin and fur of giant ground sloths have also been recovered from exceptionally dry caves in the United States and Patagonia. When some of this fur was discovered in the early 1890s it was in such excellent condition that the theory arose that specimens of these extinct ground sloths must still be alive.

Finally, before ending this survey of the various kinds of fossils, a word must be said about two specialized types that are particularly valuable to our palaeontologist time-detectives. These are fossilized dung, or 'coprolites' as they are technically called, and fossil trackways. Coprolites are quite common and give detailed information concerning the diet of many kinds of extinct animals. Trackways are of special value in telling us how these creatures used to move.

Armed with the evidence provided by these silent witnesses of the past, the palaeontologist can give us a surprisingly graphic idea of the Earth's former life. From the bones themselves, and from the rare remains of soft parts, he can tell us very often exactly what the animal was like. From the imprints of leaves and plants, and other related evidence in the rocks, he can tell us about its habitat and the kind of climate in which it lived. From coprolites he can tell us about its food and confirm the evidence of anatomy as to whether it was carnivorous or vegetarian or both. From fossil trackways he can tell us whether it was swift or slow, whether it ran, hopped, or ambled. And so on, with a thousand other details of our predecessors' daily lives.

But the palaeontologist is not a worker of miracles. He cannot, as is generally believed, reconstruct an extinct animal from a single bone. This belief is based on a misunderstanding of the laws of comparative anatomy which, although allowing certain deductions to be made about missing parts, do not permit us to be too specific about details. For instance, it is perfectly legitimate to reconstruct, say, a right leg and foot as a mirror image of a left leg and foot, but it is not therefore safe to assume that if two species agree in one particular of their skeletons, therefore they must agree in the rest. The great Baron Cuvier himself fell into this trap and formulated a law to express his convictions. This law received its most spectacular refutation in the famous case of the extinct mammal known as *Chalicotherium*. By all the rules in the book, *Chalicotherium* had the kind of teeth that were 'always' associated with hoofs, and although no remains of the feet had been found, hoofs it was assumed to have. Palaeontologists at a later date were therefore greatly discomforted to find that instead of hoofs *Chalicotherium* was equipped with enormous claws.

But the difficulties of the palaeontologist are not only those of interpretation. The way in which he extracts his 'clues' from the rocks is one of the most skilled and arduous of scientific tasks. He uses a wide selection of tools, ranging from hammer and chisel to rotary grinders and even dentists' drills. Chemicals are also used, especially with very delicate fossils, and enable the most fragile of spines and skulls to be extracted without damage.

This review of palaeontological technique will perhaps indicate some of the pitfalls and difficulties besetting the study of fossils. But the rewards are great, for fossils, even more than buried pots or written documents, are the very stuff of history. They speak not of hundreds of years, nor even of thousands, but of tens of hundreds of millions – of a time when the Earth was peopled with creatures far more mysterious and wonderful than any that live today, and when man, with all his pride of wealth and civilization, was not even dreamed of. These strangely moving relics of a past infinitely remote, some bearing the marks of violence or disease, others hinting at the joyous life activities of creatures long since vanished from the Earth, come down to us to tell of the vitality and tragedy of the primeval world. They are the most important and reliable witnesses in our story of the Earth's past, for they alone were present in those distant ages, and the drama of which they speak to us is their own.

CHAPTER 6

THE CALENDAR OF EARTH HISTORY

WE must now return to the question of Earth chronology. This will be the last general problem we shall have to consider before setting out on our long voyage through the ages to look at the changing patterns of life and landscape.

As has been said, the Earth is approximately 3,000 million years old, and this history has been punctuated by certain outstanding geological events. These events have divided the calendar of Earth history into several clearly defined Ages or Eras, which are themselves subdivided into a number of geological Periods. The arrangement of these Eras and Periods is shown on the Chart on page 58.

The earliest Eras are the Azoic and Proterozoic, which together lasted from the creation of the Earth until 500 million years ago – a total of about 2,500 million years, or five-sixths of the Earth's total age. During the Azoic, or 'lifeless', Era the Earth was still largely in a molten state, and such igneous rocks as were formed were far too hot to support any kind of life. During the Proterozoic Era the earliest life forms were already stirring in the seas. With the Palaeozoic Era, which means 'the era of ancient life', we embark on that part of the geological record of which we can give a fairly full account, for through this and the succeeding Mesozoic ('middle life') and Cenozoic ('recent life') Eras, there is an abundance of geological and fossil evidence. We ourselves are living in the seventh division of the Cenozoic Era, known as the Holocene.

Unlike the great Eras, whose names are based on various qualifications of the Greek word *zoe*, meaning 'life', the names of the Periods are mainly based on geological formations. Thus 'Cambrian' is named after 'Cambria', the old Roman word for Wales, where rocks of this age were first investigated; Ordovician is named after rocks in an area formerly occupied by the Celtic tribe of the Ordovices;

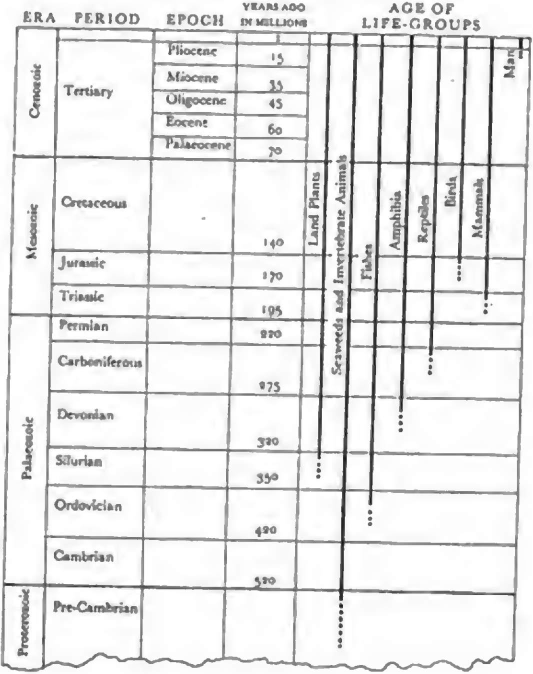


Chart to show the sequence of geological Eras and Periods, and the times of the first appearance of the various forms of life. The two parallel lines at the top of the Chart represent the Pleistocene and Holocene Epochs, or Quaternary Period. None of the divisions is strictly to scale. (Adapted from *The Succession of Life through Geological Time* by K. P. Oakley and H. M. Muir-Wood.)

Silurian after another Celtic tribe, the Silures; and so on. When we come to the Cenozoic Era, however, its subdivisions, which are known not as Periods but Epochs, are named after various qualifications of the Greek word *kainos*, meaning 'recent'. Thus Eocene means 'dawn of the recent', Oligocene 'few of the recent', Miocene 'less recent', Pliocene 'more recent', Pleistocene 'most recent', and Holocene 'wholly recent'. The term Palaeocene, meaning 'ancient dawn of the recent', is also employed to mark the period of transition between the Mesozoic and the Eocene.

This calendar of Earth history is in universal use all over the world, although other subdivisions are sometimes added, and there are occasional differences in the names of the Eras. For instance, some geologists do not agree that the Azoic Era was entirely devoid of life, and therefore use the term Archaeozoic ('primordial life') instead; while older authorities follow the plan laid down by the Italian professor Giovanni Arduino in the eighteenth century, which recognized only three main divisions named Primary, Secondary, and Tertiary. Under this system the Primary and Secondary corresponded respectively to the present Palaeozoic and Mesozoic Eras, and the Tertiary to the present Palaeocene, Eocene, Oligocene, Miocene, and Pliocene Epochs. A fourth division, the Quaternary, was added in 1830 to represent formations laid down since the end of the Pliocene, and although the names Primary and Secondary are now obsolete, the names Tertiary and Quaternary are still in common use. Very few variations occur in the naming of the Periods, the only cause for confusion being possibly the American custom of calling the earlier part of the Carboniferous the Mississippian and the later the Pennsylvanian.

The dates shown on the Chart for the duration of the various Eras and Periods are in accordance with the latest findings of Earth chronology, especially the radioactivity method, but geologists nevertheless always date events by the name of the Period in which they occurred rather than by reference to a numerical scale. This is to avoid ambiguity, for there are still many differences of opinion with regard to absolute numerical chronology. Thus when a geologist refers to rocks of the Permian Period, his colleagues are able to identify exactly what he means even if they adopt a somewhat different time scale in actual years. Subdivisions of the various Periods, referred to as Upper, Middle, and Lower, are treated in the same way, the Lower series of rocks being obviously earlier in time than the Middle and Upper, because they were the first to be laid down.

We come now to the reason why the divisions between the different Eras and Periods have been made where they are. As has been said, these were not arbitrarily fixed, but correspond with definite geological events. Moreover, these events seem to have repeated themselves in a regular rhythm throughout geological time, as if some mysterious pulse were beating in the Earth to mark the passing of the ages.

What is the nature of these events that have punctuated Earth history like the chimes of a geological clock? Their most characteristic manifestation has been an intensive period of mountain building, accompanied by an uplift of the continents and a general retreat of the seas. At the same time volcanoes have burst into life and vast masses of molten rock have been injected from below into the surface rocks of the Earth's crust. Climates have become extreme, ice-caps have formed at the poles, and the snow and hail falling on the slopes of the newly raised mountains have turned to great rivers of ice. In the biological field many new types of animals and plants have developed by the strange process known as 'explosive evolution', which we shall be describing more fully in the chapters that follow.

Since the formation of the Earth's crust there have been at least three of these episodes of intense activity. One occurred about 500 million years ago at the beginning of the Cambrian Period; another about 250 million years ago between the Carboniferous and the Permian, and a third during the Pleistocene – an episode from which we are only just emerging. There may have been others in the long ages before the Cambrian, and there are certainly traces of at least one Ice Age dating from that time; but the great age and general inaccessibility of the Pre-Cambrian rocks, and the changes they have undergone through heat and pressure, make it impossible to give any definite verdict.

The intervals between these episodes of revolutionary activity have lasted approximately 250 million years and have been occupied by one or more of the great Eras of geological time. Thus the Palaeozoic Era began with the first episode and ended with the second, while the Mesozoic and Cenozoic Eras were contained between the second and third. Each episode with its succeeding Era seems, moreover, to have followed a consistent pattern and to have recurred in cyclic form with three clearly recognizable stages. The first stage is comparatively short and is characterized by the beginnings of volcanic activity, mountain building, and the uplifting of the continents that has just been described. The second stage, also not of long duration, sees these processes reach their peak; the world becomes a place of grand continental masses and towering mountains, bordered by comparatively small but very deep seas. New volcanoes belch fire and lava, the ground is rent by earthquakes, and extremes of climate lead to great changes in the habits and forms of life. In the third stage, which is many times longer than its predecessors, the forces of erosion gradually wear down the great mountain ranges and pile up layer upon layer of sediment in the seas. The continents become lower, the seas shallower, and the waters once more begin to gain upon the land. Climates are increasingly equable, and life settles down to a more leisurely rate of evolution. Finally, the beginning of the next great episode completes the cycle and ushers in another era of revolutionary change.

Now if this cyclic form applies to the great Eras of Earth history, can it be detected also, although in less elaborate form, in the geological Periods? The answer almost certainly seems to be that it can. The Periods, in fact, mostly behave in this respect like miniature Eras, beginning with some traces of Earth movements which quickly reach a peak and are then succeeded by a long process of erosion. The main difference between the cycles of the Eras and Periods is that the former are on an altogether larger and grander scale and probably arise from far more deep-seated terrestrial causes.

The way in which mountains are formed and continents upraised is now reasonably well understood, but the cause of the rhythmic occurrence of these events is still a subject for speculation. Various attempts have been made to relate the great ages of mountain building to happenings in outer space. For instance, the 250 million years required for the major Earth cycles is approximately the same as the time taken for one revolution of the Galaxy. This has been regarded by some authorities as significant, but how the two happenings are connected is still unexplained. A more promising hypothesis is that of thermal cycles in the interior of the Earth. This postulates alternating periods of heat accumulation and decreasing temperature below the Earth's crust, which would undoubtedly have produced the rhythmic series of Earth revolutions that are known to have occurred. But unfortunately the hypothesis merely transfers the problem, for the cause of rhythmic thermal cycles is as mysterious as rhythmic mountain building.

Whatever the fundamental cause of the Earth's regular heart beats, however, we are at least fully aware of their effects. The association of mountain building with the other phenomena of each revolution is particularly interesting, and there are numerous theories to show why the various developments should have coincided. Some of the links are obvious enough. It is not surprising, for example, that the raising of the lands and the sinking of the ocean floors leads to a retreat of the water; nor is there anything unexpected in the relationship of Earth movements and volcanic activity. What is less clear is why mountain building should produce such a marked change on climate and consequently on animal and plant life.

The climatic problem has not yet been satisfactorily solved. Some authorities suggest that vast clouds of volcanic dust are thrown high into the atmosphere during revolutionary periods and persist for a considerable time. The effect of these dust clouds is to scatter or reflect the sun's rays, thus producing colder conditions. The theory is not satisfactory, however, for the revolutionary periods give rise to arid deserts as well as ice-caps, and of these there is no plausible explanation.

Other theories are based on events in outer space such as the sunspot cycle or the phenomenon known as the precession of the equinoxes. The full explanation of these theories is too technical to be gone into here, but they are based on the general principle that a number of cosmic factors exist which regularly influence the Earth's climate. When these factors are, as it were, all pulling in the same direction, they produce different climatic results on the Earth to when they are working in opposition. But there is still no clear reason why such results should coincide with episodes of mountain building.

Having outlined the various fixed 'dates' in the calendar of Earth history, there remains only the problem of assigning rock formations to their appropriate Periods. This can often be done by the radioactivity method already described, but there are also a number of useful ways of correlating formations with others in different areas that are suspected of being of roughly the same date. A double check is thus obtained, and we can get a picture of events that have happened at the same time in different parts of the world. Methods of correlation are based partly on geological evidence and partly on information derived from fossils.

To take first the purely geological evidence. The simplest method is obviously to be able actually to trace a rock stratum from one point to another. Even though the type of deposition may vary from point to point we can then usually say with safety that the two ends of the stratum are of the same date. Unfortunately, however, this is seldom possible, except in very limited areas, and geologists have to fall back on other criteria. For example, valuable clues are provided by rock strata being laid down in similar sequence in different areas, or being affected by the same kind of heat and pressure changes, or, in the case of sedimentary rocks, by their similarity to other strata derived from the same source. But none of these methods is a very great improvement on direct tracing, for their validity is still restricted to neighbouring lands. For world-wide correlation the most important method always has been, and probably always will be, by reference to 'index fossils'.

One of the most valuable characteristics of biological evolution is that, although its rate has varied greatly from age to age, it has never changed a great deal from area to area. On occasion, of course, evolution has been somewhat more advanced in one area than in another, but never so greatly as to throw the whole great process out of step. Thus, generally speaking, a rock formation bearing certain types of fossils in one continent may be safely correlated with one bearing similar, if not identical types, in another. This is one of the great ways in which palaeontology has aided our study of Earth history. It has enabled us to relate the great rock formations to particular Periods in geological time, and to gain a far more accurate picture than would otherwise be possible of the way the Earth has evolved.

The calendar of Earth history, built up patiently by such means, reveals some astonishing facts. For example, of the 3,000 million years since the Earth's origin only the last third has left any traces of life. The great natural class of the mammals, which contains all the animals most familiar to us, has been prominent for only 70 or 80 million years; this is only about half of the period occupied by the great reptiles, and less than a tenth of the whole history of life. Man, the most advanced of the mammals, and the latest experiment of the evolutionary process, has a history that can only be reckoned in thousands of years.

Such figures are almost impossible to comprehend, but they can perhaps be simplified by an illustration. If we imagine that the whole of the Earth's history were compressed into a single year, then, on this scale, the first eight months would be completely without life. The following two months would be devoted to the most primitive of creatures, ranging from viruses and single-celled bacteria to jelly-fish, while the mammals would not appear until the second week in December. Man as we know him would have strutted on to the stage at about 11.45 p.m. on December 31st, and the age of written history would have occupied little more than the last sixty seconds on the clock.

The calendar of Earth history, then, like the immensity of astronomical space, gives us a valuable lesson in humility.

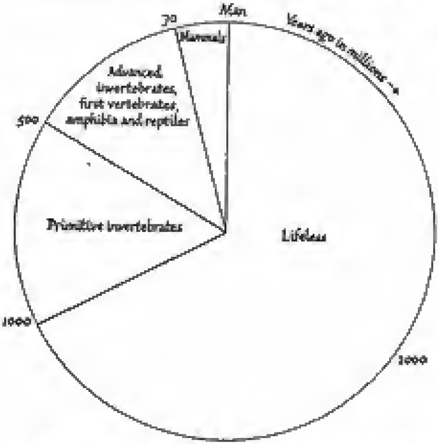


Diagram to show the relative length of the different stages in the development of life. The Age of Man is represented by the single vertical line

In the chapters that follow we shall walk down these long avenues and pause to wonder at the fantastic primeval zoo that is housed in such splendid profusion and vigour along our route. Many of these creatures have long since become extinct; they are our predecessors in the adventure of life, Nature's lavish failures who were destined never to enjoy our own evolutionary success. For this reason alone they are deserving of our most compassionate interest.

PART TWO

The Procession of Life

CHAPTER 7

WHAT IS LIFE?

BEFORE we can attempt to follow the development of life on Earth there are two main problems to be considered. The first is to find, if we can, a satisfactory definition of the word 'life'. The second is to look briefly at the workings of organic evolution. Bound up with these questions is the ancient enigma of life's origins and the problem of whether evolution can be said to have any discoverable purpose or goal.

The question 'What is life?' seems at first almost too obvious to need an answer. I am alive, this book I am reading is *not*. A cow, and the grass it eats, although belonging to the different groups 'animal' and 'vegetable', are both alive: the pail into which the cow is milked, however, in addition to being 'mineral', is very obviously 'dead'. Apparently, therefore, there are two distinct categories; there is the organic, popularly exemplified by the Animal and Vegetable Kingdoms, and the inorganic, exemplified by the rest of nature. It should, one would think, be a simple matter to sort things into one compartment or the other.

Until recent years this was in fact the general opinion. A hard and fast line was drawn between living and non-living matter. Life was regarded as a special process carried on against a background of dead rocks and minerals, and the main problem was to discover how living things had intruded into this inanimate scene.

It is astonishing to consider in retrospect the extent to which this dual theory of nature has kept its place in human thought. Man seems to have hung on to the barrier between living and non-living matter with extreme tenacity, and apparently without any suspicion that it might be artificially erected. As a result the question of the 'origin' of life has been, and still is, a fundamental enigma to the vast majority of mankind. In religion it has led to the many charming legends of the creation, in which God is assumed to have produced the different classes of living things by a kind of celestial conjuring trick. In science it has produced some almost equally picturesque theories, such as those of Hieronymus Richter and Lord Kelvin, which suggested that life, in the form of tiny living spores or 'cosmozoans', was driven here from other planets by the radiation pressure of starlight – a theory which incidentally only served to transfer rather than to solve the problem.

During the last few years, however, a more radical approach has been made to the whole question. It is beginning to be suspected that the difference between living and non-living matter, between the animal and the vegetable on the one hand, and the mineral on the other, is less a difference in kind than in complexity. In other words, it is felt that 'living' matter may have evolved from 'dead' matter by as natural and uninterrupted a process as that which has seen the evolution of man via an ape-like ancestor from a Devonian air-breathing fish.

To understand this revolution in scientific thought it is necessary first of all to consider the features which distinguish organic from inorganic matter. The differences are not nearly as great as was once supposed. We will begin by cataloguing the various qualities which are normally said to characterize living things. These are, firstly, constant change – the life process can never stand still; secondly, the transformation of latent energy in the form of fuel into apparent energy in the form of work; thirdly, the replacement or repair of outworn tissues; fourthly, the ability to react to hostile influences or changes in environment; fifthly, the power of multiplication and growth; and finally, in more advanced life forms, the capacity for memory and intelligence.

Now it is a significant fact that nearly all these qualities are present also in non-living substances. The constant change of all forms of matter is a basic assumption of modern physics, and the behaviour of crystals fulfils every other item in the specification except possibly memory and intelligence. These last qualities are not, however, present in primitive forms of life, and cannot therefore be regarded as indispensable to the definition of living substance. Rather they are the outcome of a long process of evolution, and represent a complex degree of organization, not a fundamental difference in quality.

The difficulty of drawing a definite line between living and non-living matter becomes even greater when we begin to explore the strange no-man's-land revealed by the electron microscope. The electron microscope is an instrument which does not, like the ordinary optical microscope, make use of light rays. Instead it uses cathode rays, replacing a beam of light by a stream of electrons, and lenses by electromagnets. This gives it the advantage of a greatly increased resolving power, allowing far smaller objects to be studied. The only disadvantage, if such it can be called, is that as light waves are not used the objects studied by the electron microscope cannot be directly observed with the eye, but must first be registered on a photographic plate.

One of the most interesting contributions of the electron microscope to science is the knowledge it gives us of those minute substances known as filter-passing viruses, which lie on the borderlands of life. Viruses are now known to be responsible for many kinds of diseases in man, animals, and plants, but their exact nature is still in doubt. Their most extraordinary property is that they behave at different times either as animate or inanimate things.

The first discovery of the existence of viruses was made by the Russian botanist Dmitry Ivanovsky in the early 1890s. He was investigating a disease of the tobacco plant which caused a mosaic-like mottling of its leaves. In one of his experiments he passed some of the juice from a diseased tobacco plant through a germ filter, thereby producing a clear liquid that was entirely free of visible germs. But when he reinjected this liquid into a healthy plant it immediately contracted the mosaic disease, thus proving the existence of some minute substance in the liquid whose nature was not known. This substance has since been identified as the tobacco mosaic virus.

During the last twenty years or so some extraordinary discoveries have been made about this and many of the other types of viruses. In 1935, for example, the American biochemist W. M. Stanley succeeded in isolating a sample of pure tobacco mosaic virus from the juice of an infected plant. To his astonishment he found that the virus was not alive in the ordinary sense of the word, but had all the attributes of a crystalline solid. Its chemical constitution could be analysed and it even formed regular shapes like the crystals of other chemicals such as salt or sugar. In its isolated form it certainly did not possess the power of reproduction so typical of living things; but – and this is the important point – when reintroduced into a healthy tobacco plant after a long period as an inanimate crystal it literally 'came alive', infecting the plant with mosaic disease and rapidly multiplying like an ordinary primitive organism.

The analysis of viruses seems therefore a promising line of attack if we are to arrive at an answer to our question 'What is life?' Recent research has, in fact, gone far towards confirming this opinion. It is now known, for example, that viruses are composed of the substances known as proteins, which are the fundamental constituents of all living cells. The cell material itself is called protoplasm; it is the raw material of life, and is built up in different degrees of complexity into all the varied forms of living things. But although proteins are essential to life, and in one sense actually *are* life, they are themselves strictly chemical entities. Their organization is complex, but the substances of which they are composed, known as amino-acids, are comparatively simple. Many of these amino-acids have actually been synthetically produced in the laboratory.

The implication of these facts is that the condition of matter which we call 'living' does not necessarily belong to an entirely separate order of nature. Rather it could be regarded as just one of the stages in the growth of more complex substances from simpler ancestors. We nowadays accept without question the evolution of the higher forms of life from the lower, but we somehow resist the idea that life itself could have evolved just as logically from an earlier non-living stage. Yet surely there is a greater mental jump to be made from the mind of a Shakespeare or a Beethoven to a drop of primitive protoplasmic froth, than there is from this same froth to the strictly chemical stage preceding it? Science seems to be moving to the inevitable conclusion that 'life' must be defined not as a unique and distinct phenomenon, but as a particular degree of organization in the basic materials of the Universe.

If this is the case we can offer a far more beautiful and satisfying account of the 'origin' of life than has hitherto been possible. We can imagine the primitive life-stuff being chemically developed in the shallow water of the first seas as naturally and inevitably as the Earth had previously evolved by physical laws from a wisp of stellar gas. We can feel this great process continuing through the long ages of geological time, slowing a little here, hurrying a little there, like the different movements of a great symphony. But always through the varying rhythms we shall find the same irresistible momentum, giving evidence of a force that has organized the non-living into the living, the instinctive into the mental, and which must even now be driving us forward to new and unimaginable ends.

Of course, it may be said, this is all very romantic and attractive, but are there any scientific grounds for believing it to be true? The answer to this question may perhaps be clearer when we have considered the picture of evolutionary change which this book aims to present. Meanwhile, with regard to the first appearance of life on Earth, there is certainly good reason to believe that it resulted from some kind of chemical reaction in the oceans.

We have already tried to picture the conditions in early geological time when the waters began to run over the cooling rocks and collect in hollows to form the first seas. These seas, incidentally, would have been fresh, not salt, for the saltiness of present-day sea water has resulted from the long accumulation in the ocean basins of salts in solution washed down from the land by the great rivers. When the first seas were formed this process had not been long enough under way to produce any appreciable salinity. There may, however, have been carbohydrates dissolved in the sea, formed by the action of the water on carbon compounds in the Earth's crust; also the warm moisture-laden atmosphere would probably have contained such gases as carbon dioxide, chlorine, and nitrogen. Under such conditions additional carbohydrates would probably have formed, and these, combining with the nitrogen, would have created the typical compounds found in amino-acids and proteins. In the final stage a chemical agitator such as phosphorus may have touched off the process that we now call life.

These possibilities are still, of course, highly speculative. The final test will be made if material with the characteristic life-activity of ordinary protoplasm can be artificially produced in the laboratory. We have seen that a step has already been made in this direction with the manufacture of synthetic amino-acids. And it has been claimed recently from Germany that certain amino-acids can now be artificially combined to form albumen, a recognized protein. The production of synthetic proteins in this way is a task involving immense technical difficulties, but scientists are confident that in time all the problems can be overcome. If they are proved correct the mystery of life as a physical process will be well on the way to solution.

CHAPTER 8

LIFE'S FAMILY TREE

We must next look briefly at the second topic raised in the foregoing chapter – the nature and workings of organic evolution. No one of an imaginative turn of mind can fail to be impressed by the immense diversity of living things that now inhabit the Earth. The size and strength of the elephant, the fragility of the butterfly, the exquisite hues of flowers and birds, the obscure life-activities of the virus and the microbe – all these arouse in us a profound sense of wonder. How and why did these creatures develop to their present forms? Why do they behave as they do, and what special role do they fulfil in the intricate pattern of nature?

We must also take into account those mysteriously different forms that lived long ago and are now extinct. The diversity of modern animals is as nothing compared to that multitude of vanished creatures who played the leading roles in the dramas of the past. Their bones silently testify to a prodigality of invention and a vitality of experiment in ways and means of existence that it is quite impossible to grasp.

Long before the nature of fossils was fully understood, men were pondering on the diversity of life and trying to find an explanation of the many problems it posed. Not surprisingly they hit on the simplest solution first: that the different kinds of animals had been unchanged from the beginning, and that they had been individually moulded from the dust of the Earth by a process of special creation. This belief was common among primitive peoples and was later incorporated in religious systems all over the world. Before the end of the eighteenth century only a handful of thinking men realized that it was an unlikely, and in any case an inadequate, explanation.

The most inescapable difficulties resulted from the researches of the French naturalist Baron Cuvier on the true significance of fossils. In a world containing only living forms it had at least been possible to believe in the idea of a special creation of all the animals in 4004 B.C., and that they had kept the same appearance ever since. This view was accepted at the time by science as well as religion, and had even been incorporated by the great Swedish naturalist Linnaeus in a pronouncement which became somewhat pompously known as 'the dogma of the stability of the species'. This asserted categorically that 'the existing species of animals are now as they were created in the beginning'.

Cuvier's fossil bones disrupted this theory completely. As he continued his researches, more and more species came to light that had obviously had no part in the Biblical creation. Yet in an unaccountable way they did seem to have a family likeness to some kinds of existing animals. It was almost as if a similar but earlier creation had taken place, and that every one of its creatures had perished in some appalling and all-engulfing catastrophe, only their bones remaining to tell the tale.

Naïve as this theory may seem to us now, it was the one that Cuvier adopted. But he soon found that the accumulating weight of fossil evidence made it necessary to postulate not one additional creation before that described in the Bible, but three. Each of these creations, he said, must have been similarly brought to an abrupt end by a universal cataclysm. As a result of this theory Cuvier had obviously to cast around for a new scale of geological time, for it was apparent that 6,000-odd years was not a sufficient allowance for even one additional creation, let alone three. Fortunately he found a new scale ready to his hand; it was that proposed by his fellow-countryman the Comte de Buffon, which we have already described in Chapter 4. Cuvier must have been delighted to find it of just the length to accommodate comfortably his three additional creations and the cataclysms that brought them to an end.

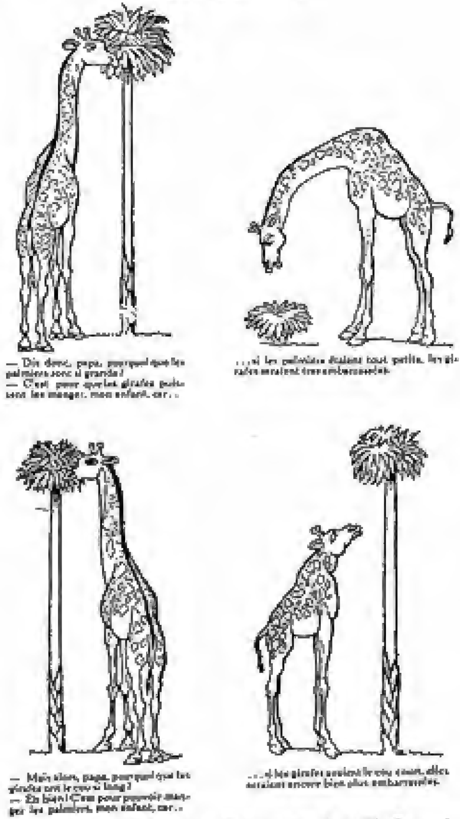
Concisely stated Cuvier's theory now amounted to this. God had created the world sometime about 80,000 years ago and peopled it with the animals of the first creation.

These had been mostly fish and other sea creatures, and a number of primitive amphibians. After the first cataclysm a second creation had occurred which had been concentrated mainly on reptiles. But God had not regarded this as much more satisfactory than the first, and, after a second cataclysm, yet a third creation had been devoted almost entirely to the mammals. Finally, a third cataclysm followed by the Biblical creation, had led to the first appearance of man and to the diverse types of plants and animals we know today. These would remain in existence under man's domination until God in his wisdom decided to repeat the process of liquidation.

Almost without realizing it Cuvier had established the idea of the geological eras and paved the way for the synthesis that was to follow. This was achieved shortly after his death by two of the greatest men in the history of natural science, the geologist Sir Charles Lyell and the naturalist Charles Darwin. We have already seen how Lyell established the doctrine of uniformitarianism, which stated that, given sufficient time, the ordinary forces of nature would account for every change in landscape since the origin of the Earth. This principle, as Darwin quickly saw, removed the necessity for Cuvier's cataclysms altogether, and pointed the way to a new conception of life and the way it had developed. If the idea of cataclysms was simply replaced by an infinitude of time there was no reason why living things should not have developed by a slow but inevitable process similar to that which had sculpted the surface of the Earth. This hypothesis led to Darwin's classic investigation into the mechanism of evolution, culminating in 1859 in the publication of his *Origin of Species by Means of Natural Selection.*

Darwin's work on evolution was undoubtedly aided by the theories of several of his predecessors, especially those of Lamarck, who had advanced a general theory of evolution as early as 1809. This maintained that evolutionary changes took place by a process known as 'the inheritance of acquired characteristics'. For example, the long necked giraffe evolved from shorter necked ancestors because the individual giraffe, by constant stretching after leaves on tall trees, acquired a slightly longer neck. This was transmitted to its offspring, and so on down the generations. Unfortunately there is no conclusive evidence that this kind of inheritance can take place, and it led its followers into the kind of difficulty shown in the caricature on the next page.

Darwin, therefore, was the first to formulate the theory of evolution as a comprehensive doctrine that would withstand scientific investigation and criticism. The theory itself is now too well known to need a detailed exposition, but can briefly be summarized as follows. All living things on the Earth are members of the same great family and have developed to greater and greater complexity from the simpler forms of life that have preceded them. Ultimately every creature must be able to trace back its ancestry to a form of life as simple or simpler than that now represented by the lowliest known organisms. The different species, with their diverse forms, have differentiated through the long aeons of geological time by a process known as 'natural selection'. This process depends on the fact that every individual is slightly different from every other individual, even in the same species, and that individuals from time to time tend to produce definite heritable variations (or 'mutations' as they are technically called) caused by changes in the germ cells giving rise to the next generation. In each generation in any given area the individuals whose variations have best fitted them to their environment are the ones most likely to remain alive and reproduce themselves. Nature can therefore be said to have automatically 'selected' that type for survival from among its less well equipped rivals. The process is repeated in each generation, the survival qualities being continually selected, the others being discarded. But as the qualities selected will vary with each creature's environment, different strains are established, each with its own particular kind of specialization. It is the differentiation of these 'selected' strains that leads to the



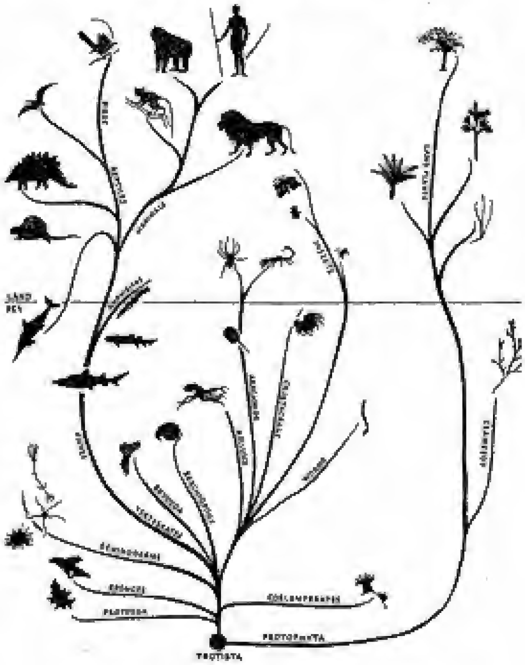
Lamarckism in caricature, by Caran d'Ache. From Umbgrove's *Symphony of the Earth* (After M. J. Sirks) establishment of species, each perfectly adapted for the kind of existence it habitually leads.

Sometimes evolution has gone on at a slow and even pace, while sometimes there have been great outbursts of evolutionary activity leading to a sudden increase in the number of species. This phenomenon, known as 'explosive' evolution, has coincided with the great rhythmic upheavals in the Earth's crust which were described in Chapter 6. It can be reasonably explained by reference to the great changes in climate and environment that went on at these times, leading to frenzied experiments by nature to produce new types able to adapt themselves to the altered conditions.

Often at such moments a species or group of species would set off up an evolutionary blind alley, specializing on some quality such as excessive size or over-developed armour in the mistaken belief that this would solve its problem of survival. Sometimes, indeed, the new specialization would succeed for a time, but eventually the species would die out through changes in the environment and the competition of creatures less morbidly developed in one particular direction. We shall meet several of these tragic failures in the pages that follow, and our knowledge of evolution will help to explain how they found themselves in their unhappy predicament.

The establishment of life's family tree by the evolutionary process is now universally recognized by all responsible scientists. The design of the tree and the lay-out of some of the principal branches is shown in the picture diagram on the following page. Despite the many gaps in the fossil record which, when they are filled, may lead to slight revisions in the placing of some of the details, the tree on the whole gives an accurate picture of the way life has developed. It remains only to outline the reasons that have proved to us that the theory of evolution must be true.

Some of the most interesting testimony comes from the science of comparative anatomy. This is another of the sciences whose development we owe to the great Baron Cuvier, and it has led to many advances in our knowledge



Life's Family Tree. Diagram to show probable relationships of the different forms of life of life's family relationships. In the illustration below are drawn for comparison the forelimbs of six quite different kinds of animals. First there is the amphibious frog; then the turtle, a reptile; next a bird; and finally three contrasted mammals – a bat, a dog, and a man. It would perhaps be difficult to imagine six more superficially different structures than the leg of a frog, the paddle of a turtle, the wings of a bird and a bat, the leg of a dog, and the arm of a man. Yet, looking below the camouflage of skin and flesh and feather, what do we find? That the fundamental skeletal structure is essentially the same, the differences being entirely those of size and proportion in the different bones.

Limbs of (left to right) frog, turtle, bird, bat, dog, and man, demonstrating kinship of vertebrate groups

These likenesses can prove only one thing – a deep-seated family relationship; they cannot be explained on any other assumption. The differences are the result of modifications of a common ancestral stock into different specialized forms of life. They were developed through geological time by the process of natural selection.

Comparative anatomy gives us additional evidence of evolution in its discovery of useless organs and structures in existing animals, which in previous times had an essential function. The best known example is the human appendix, which in our ancestors formed a necessary part of the digestive system but in us has been superseded and seems only to be a source of danger. Another of these 'vestigial' structures, as they are technically called, are the muscles of the human ear, which once controlled a wide range of movements but now can hardly be restored to any functional activity, even by long practice. There are nearly two hundred of such useless structures in the human body, and they all suggest our descent from a creature which habitually put them to some important functional use.

Still further evidence for evolution comes from the science of embryology, which deals with the history of the individual animal before birth. It is now known that the bodies of all living creatures are made up of millions of tiny specks of organized protoplasm known as cells. Yet however complicated the body pattern of the adult animal may be, it has always begun its existence as a single cell or egg. Moreover, animals of very different appearance may have very similar young. For example, worms and snails, and sea urchins and primitive vertebrates, despite wide variations in the adults, have marked likenesses at the embryonic stage of their development. These likenesses imply descent from a common ancestor, and are another important proof of the truth of evolution.

The workings of evolution can be clearly seen in the fossilized remains of animals buried in the rocks. As successive layers are examined we can watch the fantastic pageant of life unroll. The birth of each group is marked by a few simple, easily adaptable forms often occupying a fairly limited area. The next stage sees their increase and a gradual specialization into several distinct types as they fan out into new and varied environments. Finally, in many cases, specialization begins to run away with itself, producing bizarre and extravagant forms like the bone-headed dinosaurs of the late Mesozoic and the giant mammals of the Oligocene. These over-specialized forms, despite a transitory period of success, are doomed from the beginning to extinction. They are the side branches of life's family tree, born without hope of ever reaching upwards to the brightness of the future.

It would be out of place here to describe in too much detail the names of the various branches and twigs in the tree of life, but a word must be said about the main divisions of its trunk. We should first picture the roots of the tree as beginning in the simple protoplasmic life-stuff which was mentioned in the last chapter. The first great differentiation would then be into the Animal and Vegetable Kingdoms, which constitute the twin pillars of the trunk. From each of these radiate the main branches, which scientists call the 'phyla' from the Greek word *phulon* meaning 'race' or 'stock'. Each of these, again, is split into smaller branches called 'classes', and then into 'orders', 'families', and 'genera'. Finally come the outermost twigs of the tree, which we know familiarly as 'kinds' or 'species'.

This description of the tree of life will help us to explain the system of scientific names which students use to identify different living things. These often fill the layman with dismay, but despite their length they are really a simplification. The first naturalist to take on systematically Adam's task of naming the animals and plants was the eighteenth-century Swedish botanist Carl von Linné, usually referred to as Linnaeus. Before his time utter confusion reigned in classification methods for natural history. Animals had different names in different languages, with the result that no naturalist had the slightest idea which species his foreign colleagues were talking about.

To rectify this, Linnaeus introduced what was virtually a system of surnames and Christian names for every animal. For the word 'cat' he decided to employ its Latin equivalent *Felis*; this we can therefore regard as the surname of the animal. Then for all the various species of cat he assigned a second Latin or Greek word. Thus the lion became *Felis leo*, the leopard *Felis pardus*, the ordinary house cat *Felis catus*, and so on. In this way scientists knew that if they referred to *Felis leo* their colleagues all over the world would always know what they meant, irrespective of the local translation of the word 'lion'. The value of this convenient form of scientific esperanto can easily be seen.

Today the surnames and Christian names established by Linnaeus are referred to respectively as the 'generic' name and the 'trivial' name, the two together as the 'specific' name. Similar names are also given to the larger branches of the tree. Thus *Felis leo* belongs to the family *Felidae*, or 'cat tribe', of the order *Carnivora*, or 'flesh eaters'. This in turn belongs to the class *Mammalia*, or 'mammals', of the phylum *Vertebrata*, or 'animals with backbones'. The phylum itself is one of the thirteen great divisions of the Animal Kingdom which, together with the Vegetable Kingdom, forms the twofold trunk of the tree of life.

Many modifications have been made to the system of classification since the time of Linnaeus, but the principles in which it is constructed are essentially the same. The orderly naming of the animals and plants has enabled us to obtain a much clearer picture of the relationships of living things than would otherwise be possible. But life's family tree is not only a convenient method of pigeon-holing and docketing the various kinds of living things. It gives us also a bird's eye view of the whole of evolution and of the parts played by the many different actors in the great drama of living things. We see there not only the leading characters – the heroes and heroines and villains – but also the less dazzling performers: the comics, the character actors, and even the timid little 'extras' who play an insignificant but vital part in dressing the scene. This is the richly varied cast to which we must now turn our attention.

CHAPTER 9

THE FIRST ORGANISMS

THE first act of the drama of life was played in the coastal waters of the primeval seas against a sombre background of barren rock, deserts, and thundering volcanoes. The Earth's crust had been formed many millions of years before, and the highly charged chemical environment at the meeting place of land, sea, and air had seen the generation of the first life-stuff in the world. We have already spoken of the viruses, and said that organisms of this type may have formed the transition stage from inorganic to organic matter. We must now look a little higher up the scale and see what can be found out about the simplest organisms that truly come within the category 'living'.

The earliest characters to enter upon the scene were probably humble organisms of the natural division known to biologists as the Protista. The term Protista comes from the Greek word *protistas*, meaning 'the very first', and it was introduced by the nineteenth-century German zoologist E. H. Haeckel, to describe life-forms of the simplest structure, which could not be definitely distinguished as either animals or plants. Most of its members consist of only one unit, and they are the probable ancestors of every later example of animal and plant life. But in order to describe more fully what the Protista are like we must first examine the structure of living matter and the main differences between animals and plants.

The raw material of life, as we have already said, is known as protoplasm. This consists of a kind of living jelly composed of proteins, and is the physical basis of every living body, however large or of whatever shape it may be. But there is no such thing as a continuous mass of protoplasm; the protoplasmic jelly is always divided up into the tiny microscopic units known as cells. Each cell is contained by a cell membrane inside which the protoplasm is divided into two distinct parts – a central blob, or 'nucleus', and a surrounding body of protoplasm technically known as 'cytoplasm'. In the simplest life-forms a single cell of protoplasm develops independently as a free-living unit, but in more complicated creatures the body is built up of many cells, as bricks are used in the construction of a house. Although most cells are of microscopic size each of them can perform all the characteristic activities of living things, such as assimilation of food, chemical change, elimination of waste products, and so on.

When we study the free-living, single-celled organisms we find that they are of three main kinds. There are some that behave like animals, some that behave like plants, and others that seem to partake of the qualities of both. The difference between the animal and plant types is based partly on the nature of the membrane surrounding the cell and partly on their method of feeding. Plant cells have comparatively thick membranes made of the carbohydrate cellulose; the walls of animal cells, on the other hand, are much thinner and are usually composed of a layer of fat and protein. Another difference is that plant cells contain the characteristic green pigment known as 'chlorophyll', which enables them to use the sun's energy to combine the chemical elements of soil and atmosphere into food. This process, known technically as 'photosynthesis', cannot be performed by animal cells, which depend for their food on the work of the plants. The same fundamental reliance of the Animal Kingdom on the Vegetable Kingdom is apparent at every stage of evolution. Plants build up their food with the aid of sunlight from the inorganic substances of the Earth; animals must first take in and break down pre-existing living matter and then rebuild it in the way they need.

The unique characteristic of the Protista is that they cannot be definitely assigned to one category or the other. They are intermediate forms, part plant, part animal, and there is good reason to believe, therefore, that they belong to the very roots of the tree of life, before the first great split took place into the Animal and Vegetable Kingdoms. We shall consider first the most typical example of these primitive, undifferentiated organisms, which are well known to scientists and laymen alike – the bacteria.

The bacteria are the smallest organisms that can be seen with the optical microscope. To many people they represent mainly the unseen causes of disease, and indeed many of the most dreaded diseases of men and animals are due to the activities of bacteria. Bacterial action is the cause of such scourges as tuberculosis, typhoid, dysentery, cholera, leprosy, and oriental plague, to name but a few. But to regard bacteria exclusively as malignant influences is to do them an injustice. The vast majority of them are not only the friends of man but are essential in a hundred different ways to the existence of life itself. For example, it is bacteria that preserve the fertility of the soil, without which no form of plant or animal life could survive.

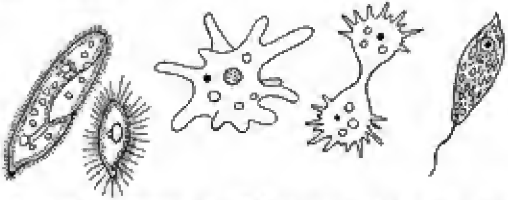
Bacteria in general are of three basic shapes. There is the spherical or 'coccus' shape, the rod-like or 'bacillus' shape, and the spirally twisted 'spirillum'. If a bacterium rod were magnified to the size of a pencil, a man on the same scale would be over twenty miles high, while some of the cocci are so small that over a quarter of a million of them could be placed together on a pin head. All of them are single-celled, and they multiply by dividing in two, a process which in favourable conditions occurs every twenty or thirty minutes. The bacteriologist Felix Löhnis has worked out some interesting figures to show what immense numbers of bacteria this constant division of cells can lead to. Assuming a rate of division of once every half-hour, at the end of one hour there would be four cells, at the end of two hours sixteen cells, and at the end of three sixty-four. As time goes on, the figures of the series reach spectacular proportions. After fifteen hours about 1,000 million bacteria will have been produced from a single parent, and in double that period these will have so increased that their bulk will occupy about 4,500 cubic yards, which is about the capacity of a goods train of 100 wagons. Fortunately for us the conditions favouring such a rate of increase occur very seldom in nature, and then only for very short periods, so there is little danger of our being crowded off our planet by the accumulating legions of bacteria.

The structure of bacteria is more easily studied than that of the still mysterious viruses. They consist, of course, of protoplasm, but opinion is divided as to whether they possess the true nucleus which is typical of most single-celled organisms. In some of the larger kinds of bacteria a nucleus has been observed, but there is now some doubt as to whether these kinds should be classified as bacteria at all. With the others the nucleus seems to be replaced by little granules of nuclear material, technically known as 'nucleoproteins', which are evenly distributed throughout the whole organism instead of being concentrated into a single blob in the middle.

One would hardly expect that creatures so minute would have left any fossil record in the tangled Pre-Cambrian rocks of long ago. Yet there is now some fairly conclusive evidence that these creatures did exist at that time. Pre-Cambrian rock formations in Michigan show traces of tiny dark objects which may well be the remains of iron-depositing bacteria closely related to a species still living today. Small spherical bodies like those of a minute coccus have also been identified in the great Pre-Cambrian formations of Montana. It is strange to think that traces of a creature so small and fragile could have been clearly preserved for nearly 1,000 million years.

Bacteria, as we have seen, belong to that indeterminate region between plants and animals. But they are not the only organisms to do so, and another group, rather more advanced than the bacteria, is equally fascinating to the biologist and the Earth historian. The members of this group make up the natural class of the Flagellata, and are characterized by a long whip-like projection of protoplasm known as a 'flagellum'. This word is derived from the Latin verb 'to whip', and the flagellates use the flagellum to lash their way through water or other fluids with a jerky but reasonably effective motion.

It would be quite impossible definitely to assign many of the flagellates to the Animal or Vegetable Kingdoms. Some possess chlorophyll and can derive their nourishment directly from their environment by photosynthesis. Others have lost their chlorophyll and take in particles of food through their cell membranes like typical one-celled animals. Several kinds have managed to make the best of both worlds and can feed either like animals or plants. An excellent example of this is the little flagellate known as *Euglena*. In a natural state *Euglena* feeds by photosynthesis and will live quite happily in an open dish well exposed to the light. But if it is placed instead in a nutrient solution in total darkness it will



Three primitive organisms. On the left are two paramecia; in the centre, two amoeba (one in process of division); on the right, *Euglena*

change over to the animal system and take in food through its surface 'skin'.

Enough has now been said to give an idea of the occupants of this natural no-man's-land between plants and animals, and we must next explore the two great kingdoms that lie on either side. On one side of the line we shall find the vast and varied world of the Protophyta, or 'first plants'. Of these the most important group are the Algae, comprising over 18,000 different species. They range from the scum of freshwater ponds to the great ocean seaweeds, some of them over 100 feet long. On the other side of the line are the Protozoa, or 'first animals', comprising such creatures as the famous amoeba of the laboratory and the biology class, and the paramecium, or 'slipper animalcule'. A little higher up the scale come the first great phyla of the many-celled creatures, such as the sponges, polyps, and medusae.

Both Animal and Vegetable Kingdoms will occupy our attention in the following pages, but the plants, being static and not gifted with the same capacity for mental development as the animals, will necessarily be of secondary importance to the story. For this reason we shall reserve a summary of their history for a later chapter and pass on here to the two most interesting of the primitive protozoans, the amoeba and the paramecium, both of which are common animals of today.

The amoeba is popularly regarded as the simplest of all organisms, but in fact it shows a great advance on both the bacteria and the flagellates. In comparison with these it is quite a complicated creature and is reasonably specialized for its particular way of life. There are several species of amoeba, some measuring half a millimetre across and therefore being visible to the naked eye; but the commonest form, the freshwater amoeba, is too small to be seen without the aid of a microscope. It follows the ordinary pattern of single-celled animals, having a nucleus surrounded by a mass of cytoplasm. The whole is contained in a thin cell membrane through which it can take in water and food particles.

The amoeba reproduces by dividing its nucleus and cytoplasm into two, the separate parts then becoming a pair of individual amoeba. But if it is artificially divided so that the whole nucleus is contained in only one half of the cytoplasm, an interesting difference can be observed. The part containing the nucleus will grow again to its former size and will soon begin to reproduce itself by the customary method of cell division. But the other half, having no nucleus, will be unable to carry out properly the normal amoeba life-activities. For a little while it will move about without apparent inconvenience, but eventually it will die, for it is unable to digest its food, or grow, or reproduce. This proves the essential importance of the nucleus, which apparently acts as a chemical governor of the whole organism.

The amoeba has no front or back end and can progress in any direction with equal ease. It does this by pushing out in front of it from any part of its body a small blunt projection of cytoplasm known as a pseudopod or 'false foot'. As part of its body mass flows forward to form the pseudopod the amoeba itself advances. Then a new pseudopod is thrown out from an adjacent area and the process is repeated. The animal does not, however, continue for very long in any one direction, but is constantly 'tacking' to left and right.

Feeding is equally simple, minute particles of animal and vegetable matter being surrounded on each side by pseudopods and then incorporated into the cytoplasm. Here, with the water surrounding them when they were 'eaten', they form a little blob called a 'food vacuole'. Chemical processes in the amoeba's body are used to digest and assimilate the contents of the vacuole, which then disappears. It would be difficult to devise a simpler or more effective way of living than that practised by these humble microscopic relations of ours.

Compared to the amoeba, the paramecium is an extremely advanced little organism. It has a front end and a back end and a permanent shape like a slipper, which gives it its popular name of 'slipper animalcule'. It can move much faster than the amoeba for its body is covered with over 2,000 short hairs, or 'cilia', which act like oars to propel it through the water. Feeding is a much more specialized business too, for it has a definite mouth cavity in its body behind which is a gullet running down into the cytoplasm. Yet despite this comparatively elaborate structure the paramecium is still too small to be identified with the naked eye.

Unlike the amoeba, the paramecium has not one nucleus but two. The smaller of the nuclei seems to be largely connected with the reproduction processes. Reproduction in the paramecium takes two forms. The first is by the ordinary method of cell division which can be seen in the amoeba, but the other marks the beginnings of sexuality.

There are no clearly differentiated males and females among paramecia, so sexual reproduction between individuals of the same strain does not occur. But it often does take place when groups of individuals of different strains are put together. Each paramecium adheres to its mate of the complementary strain and they exchange portions of their small nuclei through their mouth cavities. They then separate and go through a number of divisions, the advantage of the method being that hereditary possibilities are transferred from two sources to the new paramecia that result.

The reader may with reason ask why the amoeba and paramecium, being modern animals, have been given so much space in a chapter devoted to the early history of life. The answer lies in the great rarity of fossil remains in Pre-Cambrian formations, which makes any direct discussion on these early organisms impossible. Great outcrops of the rocks themselves are by no means uncommon, however, and occur not only in such famous sites as the Grand Canyon of Colorado, where the Colorado River has cut a mile-deep cleft in the plain, but in Africa, Australia, Canada, Scandinavia, India, Siberia, South America, and even in Anglesey, in the Torridon sandstones of Scotland, and in the St David's district of Carnarvonshire. It is unfortunate that these rocks have been so twisted and altered by Earth pressure as to leave no record of any contemporary protozoans, but we can reasonably assume that creatures very similar to the amoeba and paramecium may have lived in Pre-Cambrian times. This guess is supported by the fact that such simple and comparatively unspecialized creatures tend to survive almost unaltered for many millions of years. It is usually the highly specialized types that perish and are superseded.

Although they are modern types of animals, the amoeba and paramecium may therefore be regarded as excellent understudies to fill in a gap in the fossil record. They demonstrate the first tentative specializations of living things – the transition to more complicated methods of feeding and locomotion, the creation of a stable bodily structure, and the growth of sexual activity from primitive division within the unit cell. We are now free to go on to the more highly evolved species of early life – species which have left actual fossil remains to speak in the incomplete but moving language of tombstone epitaphs, or ancient and faded parish registers, of their life and death in the Palaeozoic seas.

CHAPTER 10

THE AGE OF INVERTEBRATES

BEFORE the Cambrian Period little is known about the geography or climate of the Earth. The first seas were probably shallow and widespread, and we can tell from the scarred surface of many of the rocks that on at least two occasions ice sheets and glaciers advanced from the poles towards the equator. Otherwise we know nothing, for the rock record has been badly distorted by time and Earth-pressure, and there are no proper index fossils to aid us in our speculations.

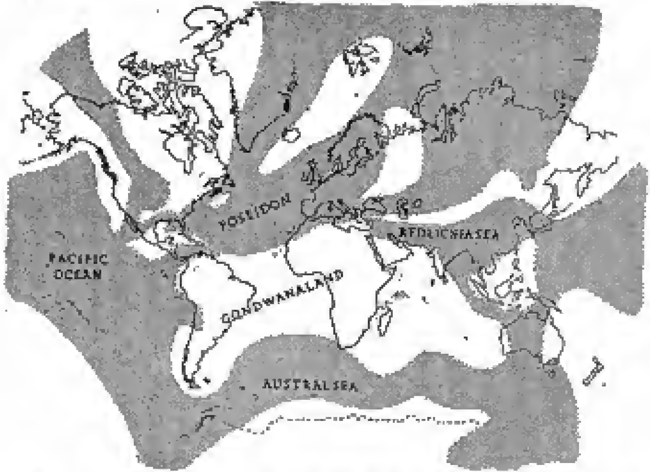
But with the opening of the Cambrian Period, which occurred about 520 million years ago, we find that the story becomes much better documented. Our main sources of information are the varied fossil remains that now begin to appear in increasing numbers. The most likely cause of this sudden appearance of fossils after 1,000 million years of an almost completely blank record is that a great many creatures existing at that time began to develop a skeleton or shell, enabling their remains for the first time to be clearly preserved and studied. As a result a sudden flood of light was thrown on the primeval scene. It was as if a curtain had been miraculously lifted to reveal the progress of a drama that had hitherto been hidden from our gaze.

Although it seems probable that the vast majority of Cambrian animals possessed shells, or some form of solid structure, they all belonged to the great natural division of the Invertebrata, or 'animals without backbones'. In fact this Period, with the following Ordovician Period, is popularly known as the Age of Invertebrates. It lasted for about 200 million years and saw the domination of the Earth by creatures that now occupy an extremely lowly place in the natural scheme. Life, moreover, was still entirely restricted to the water. The continents, with their high mountains and dusty plains, were barren and deserted, without a tree or a bush, or even a blade of grass. Only an occasional patch of moss or lichen on the inter-tidal rocks broke the monotony of this sombre and forbidding scene.

Before describing the invertebrates themselves we must first explain how the new abundance of fossils has enabled us to learn about the distribution of land and sea in those distant times. The map on the following page shows the latest conception we have of Cambrian geography. It is known as a palaeogeographical map, and is built up by noting where fossils of Cambrian age occur. These areas must at the time have been covered by sea water, for there were no land animals to heave their imprint on the rocks. The other areas, where no fossils occur, must have been composed of dry land. In later times, when life began to invade the land, the obvious differences between land and sea fossils indicate the broad outlines of Earth geography in a similar way. Land fossils can even be used as clues to more detailed knowledge. For instance, the discovery of similar land fossils in areas now separated by water suggests that there may once have been a strip of land to connect them. Conversely, widely different fossils in adjacent areas may indicate the former presence of some local barrier such as a mountain range or sea-covered straits.

We can see at once from the palaeogeographical map how very different was the geography of the Cambrian Period from that of the Earth today. Asia was almost completely submerged under two vast oceans known respectively as Poseidon and the Redlichia Sea; about half of the United States and more than half of Australia were under water; and an enormous southern continent known as Gondwanaland extended from western South America to Australia, embracing the whole of what are now the South Atlantic and Indian Oceans. The exact definition of these ancient coastlines in areas now covered by the sea is of course impossible, mainly because we have little or no knowledge of the fossils that lie buried under the present ocean floors; but the coastlines marked over present-day land areas are as authentic as painstaking research can make them.

In addition to the help they give us in palaeogeography,



Geography of the Cambrian Period, superimposed on an outline map of the modern world. Shaded areas indicate sea, white areas land.

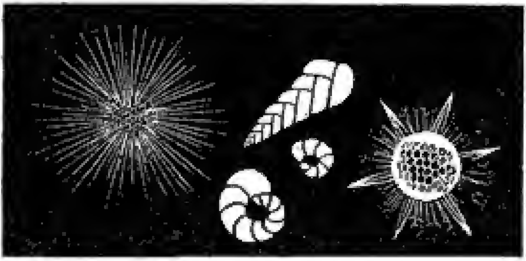
fossils can tell us a great deal about the climates prevailing in these ancient lands. The types of creatures found give a clue to the kind of environment that they would naturally need, while their distribution often shows whether conditions in different parts of the world were equable or extreme. Thus reefs of Cambrian 'coralline sponges', which were animals requiring fairly warm water, are found in fossilized form in such remotely separated areas as Greenland, Morocco, and the Antarctic continent. This suggests that the Cambrian climate was probably fairly warm and that there were not great extremes of temperature between the tropics and the poles. Similar methods can be used for deducing the probable climate in all the geological Periods down to the present day.

But we must now return from this excursion into palaeogeography and look at some of the fossil creatures of the Age of Invertebrates. By the beginning of the Cambrian Period all the main natural groups of invertebrates had already developed from the primitive kinds of organisms described in the previous chapter. There are twelve of these groups in all, comprising every division of the Animal Kingdom except, of course, the backboned animals. These last, like all star performers, were to reserve their entrance for a later scene.

The first group of invertebrates is represented by the microscopic creatures known as Radiolaria and Foraminifera. Both these belong to the natural phylum of the Protozoa, but, unlike the protozoans already described, many of them possessed tiny shells of siliceous or calcareous material. The next group is the Porifera, or sponges, which contains some of the most primitive kinds of many-celled creatures. Then come the Coelenterata, represented especially by the 'jelly-fish'; the Brachiopoda, or 'lamp shells' (so named from their resemblance to a Roman lamp); the Echinodermata, containing the starfish, sea urchins, sea lilies, sea cucumbers, and extinct cystoids; the Arthropoda, including the crustacean 'shell fish', insects, and spiders; and the Mollusca, or true shell fish, including the oysters, snails, and squids, and the two famous extinct groups known as the ammonites and belemnites. Finally come four phyla of

Vermes, or worms, and a rather neglected little phylum called the Bryozoa, or 'moss animals', whose modern representatives are sometimes mistaken by seaside visitors for seaweeds.

In the short space at our disposal it is impossible to discuss this vast assemblage of animals in anything like adequate detail. Moreover, some of the groups were not very strongly represented in early Palaeozoic times. We shall therefore restrict ourselves to a few of the most interesting members of each group, beginning with the microscopic Foraminifera



Radiolaria and Foraminifera

and Radiolaria. There is a vast number of species of these tiny protozoans, and they have persisted from the end of the Cambrian period to the present day. At some periods in the Earth's history their remains have been formed into great layers of solid rock, which have later been upraised from the ocean bed as dry land. For instance, the famous white cliffs of Dover are partly composed of the shells of foraminifers and other marine protozoans measuring less than one millimetre in diameter.

Foraminifers start their life as a blob of protoplasm, rather like the amoeba we have already described. Unlike the amoeba, however, they then begin to secrete a shell. This shell is composed of the chalky substance known as calcium carbonate, which the foraminifer extracts from the sea water. The shells themselves vary a great deal in shape and texture. Some kinds of foraminifers are content with a single chamber, but others have several, communicating with each other by openings between them. The animal occupies all the chambers and also has the power of creating new ones. This it does by pushing a mass of protoplasm through the opening of the shell and secreting a new wall. The chambers can be arranged in any form – straight, curved, coiled, or spirally twisted.

No one knows the real reason why foraminifers, or any other shelled animals, first created shells for themselves. Some authorities believe that it was as a result of increasing competition, the shell forming some measure of protection against predatory foes. Others say that the growth of a shell is primarily a chemical process and one over which the animal has no control. In other words, the calcium in the water was automatically absorbed into the animal's body when it fed and was then excreted with the other waste products. The amount that adhered to the surface or drifted away depended entirely on the animal's chemical workings, so that a shell might be formed whether its owner wanted it or not. Whatever the truth of these theories, it is certainly fortunate that so many early invertebrates secreted these shells, for otherwise there would be no fossil remains to tell us what their occupants were like.

The word foraminifer means 'hole bearer' and is derived from the small holes, or pores, in the foraminifer's shell. The animal projects long thin streams of protoplasm through these holes, which writhe about and form networks to capture and digest food. These streams of protoplasm are the equivalent of the amoeba's pseudopod and are likewise used to help their owner move about.

Foraminifers have existed in vast numbers in the seas since the end of the Cambrian Period. Most of them live deep down on the ocean floor, but a few float at or near the surface. One of the most common kinds, known as *Globigerina*, is a surface dweller, and the myriads of these tiny foraminifers that die fall in a slow and never-ending rain to the ocean bed. Here, through long ages, they have collected in drifts which are known as the 'globigerina ooze'. This accumulates at the rate of about two feet every hundred years and occupies nearly a third of the world's ocean floors – an area of over 40 million square miles.

Radiolaria are similar to Foraminifera in being protozoans of an amoeboid type. Instead of shells, however, they generally have elaborate external skeletons of great delicacy and beauty, often with long spiny projections that give them the appearance of decorations on a Christmas tree. The skeletons are mostly composed of silica which, like the foraminifer's calcium carbonate, is extracted from the waters of the sea. They often form the raw material of geological formations, and many rock layers from all ages in the Earth's history are composed of the skeletons of Radiolaria. Some kinds of Radiolaria live deep in the oceans but the majority prefer the surface waters. Like *Globigerina*, they are responsible for a rain of shells which collect on the ocean floors as a 'radiolarian ooze'. This ooze occupies 3 million square miles of the sea bed in the Pacific and Indian Oceans.

One unexpected use of these tiny sea creatures, particularly the Foraminifera, is to help human beings in the search for oil. This is because their fossil remains, being so numerous and widely distributed, are an excellent guide to the identification of rock layers where oil may be found. Samples taken from the borings at different levels are handed over to palaeontological specialists to identify any microscopic fossils they may contain. Foraminifers – or 'forams' as they are colloquially termed – are often present, and, by identifying the inaccessible rock formations below, help the operators to decide whether their prospecting is likely to succeed at that particular spot.

Next in this brief review of the Palaeozoic invertebrates a word must be said about the Porifera, or sponges. These have been common from early Cambrian times right down to the present day. They are important because they represent one of the first instances of a large number of single cells being assembled together as one large organism, with different parts specialized for different functions. Thus in a sponge only certain of the cells absorb food: they then pass on some of the food to other cells specializing in protection, reproduction, or supporting the animals body. The appearance of the sponges therefore marks the end of unlimited free enterprise for the individual cell, and the beginning of a social organization.

For many years controversy raged as to whether sponges were really animals or plants. This was because they were static and did not seem to react in any obvious way to their environment. It was thought that if they were animals they would possess the usual animal power of locomotion, enabling them to move about and search for their food. The mystery has now been solved, however, for it has been found that sponges have no need to seek their prey; they arrange that it should automatically be brought to them. This is achieved by a mechanism of whip-like flagella inside the sponge, which draw streams of water into it through the pores in its walls, and then eject them through one end. The sponge is therefore a kind of living filter, constantly absorbing its food from the currents of water that it causes to pass through its body.

The next important group is the Coelenterata, comprising in addition to the typical jelly-fish such creatures as corals and sea anemones. The word means 'hollow inside', for none of the coelenterates have any specialized internal organs. The jelly-fish and sea anemones, being entirely soft-bodied, were not good subjects for fossilization, but there are plenty of remains of corals, and also of the strange horny covered creatures known as graptolites, which were especially common at the time but are now extinct.

The name 'graptolite' comes from two Greek words: *graptos*, written, and *lithos*, a stone. It was given to the animal because fossil graptolites are usually found pressed flat in beds of shale, their hard parts appearing like a pencil or charcoal tracing on the rock. The branching 'arms' of the graptolite were made of chitin, a material not unlike that composing human fingernails, and they were often serrated along one or both edges like a saw. Inside each serration was a cup or chamber occupied by a tiny tentacled creature known as a polyp. Each graptolite was therefore really a colony rather than a single individual, and secreted its chitinous covering through the combined efforts of all the polyps in the group. The whole colony either floated in the water attached to a piece of seaweed, or anchored itself to the bottom, or to rocks; some species may even have suspended themselves by a kind of home-made gas-filled float.

The corals were built on a similar plan to the graptolites but have succeeded in surviving to the present day. The coral polyps secrete protective cups of limestone, and in some species increase by budding until they have built up massive branching skeletons. It is these skeletons that form the great coral reefs of the tropic seas, and have been upraised in a fossil state to make such famous geological formations as the Wenlock limestone of Shropshire. Several kinds of corals existed as early as the Cambrian and Ordovician Periods, but they had their heyday in the succeeding Silurian Period, when they could be found in fantastic profusion in all the oceans of the world.

Compared to the Coelenterata, the Brachiopoda are an unspectacular phylum chiefly of interest to the specialist. They are a group of small marine animals with a double hinged shell that seldom measures more than an inch or two across. The fossil remains of brachiopods are extremely common in early geological formations and, compared to graptolites and corals, they show a great evolutionary advance. Small as they are, they have a specialized digestive and nervous system, kidneys, reproductive organs, and strong muscles. They were a very persistent and successful race, more than 200 kinds of brachiopods being still alive. The primitive brachiopod *Lingula* which lives today on the shores of Japan, Queensland, and the East Indies can claim to be one of the oldest 'living fossils' in the world. Its remains are commonly found in the Ordovician rocks of 400 million years ago.

Little can be said about the four phyla of worms which existed in Palaeozoic times, for they have left very few fossil remains. All the worms are known principally from their fossil tracks, which can in some cases be assigned to Pre-Cambrian rocks; but it is usually quite impossible to say what species of worm was responsible for the evidence. The main exception is a kind of marine bristle worm that lived in the Ordovician and secreted itself a calcareous dwelling in the form of a tube. These tube-dwellings have been preserved and are often found attached in clusters to the shells of brachiopods.

All three of the remaining phyla of invertebrates are important; these are the Echinodermata, the Mollusca, and the Arthropoda. The word Echinodermata means 'creatures with spiny skins' and the group includes such familiar sea animals as the starfish of the tidal rock pools and the sea urchin – now as well known to connoisseurs of fish-food as it is to biologists. But the characteristic echinoderm of the Age of Invertebrates was the crinoid, or 'sea lily'. Sea lilies looked more like plants than animals, being clearly divided into a stem, a body, and a number of branching arms like the petals of a flower. The profusion of crinoids in the Silurian Period has caused it to be termed the 'Age of Sea Lilies', and the gorgeous colours of many of the different species must have given the sea floor the aspect of an underwater flower garden.

The Mollusca, or true shell fish, are a group that have the honour of possessing the largest creature of the Palaeozoic world. This was the Ordovician cephalopod known as *Endoceras proteiforme*, whose shell exceeded fifteen feet in length and ten inches at its greatest diameter. The word cephalopod means 'head-foot' and is given to this branch of the molluscs because of the tentacles surrounding the mouth, which appear like a bunch of limbs or 'feet'.

Of the molluscs, and in fact of all the invertebrates, the cephalopods alone have proved themselves able to survive in direct competition with the great vertebrate animals of the sea. Their vitality and aggressiveness assured them of an evolutionary success that was denied to their more sluggish relations. Their best known living representative, the giant squid, is the greatest invertebrate animal of all time; but even the smaller members of the group have shown themselves well able to hold their own in the battle for survival in the seas.

But not all the cephalopods have enjoyed this success, and two of the kinds most common in prehistoric times are now extinct. These are the ammonites and belemnites which, although they belong to a much later period than the Age of Invertebrates, will be considered here to complete our picture of the famous shell fish of the past. They reached their peak in the Mesozoic Era, when they appeared in fantastic variety and profusion. Their fossilized shells can be picked up by the dozen on the shore at such places as Lyme Regis in Dorset and Whitby in Yorkshire, where there are outcrops of the shale beds known as the Blue Lias. At Lyme Regis the fossil ammonites are so easy to come by that the smaller and more graceful examples are mounted in rings and sold to tourists as souvenirs. The belemnites are shaped like miniature projectiles and are sometimes mistaken by the uninitiated for thunderbolts; in fact their very name comes from the Greek word for a dart.

Nothing is known about the soft parts of the ammonites, but a certain amount can be deduced from their living relative, the pearly nautilus. This creature lives in the coastal waters of the Pacific and Indian Oceans and has a large coiled shell measuring up to eight inches across. The shell is divided into a series of chambers, each one slightly larger than the last. These are added one by one to a single original chamber as the animal increases in size. The nautilus itself always occupies the last and largest of the series, walling up each old chamber behind it as it moves to increasingly commodious quarters. A similar procedure was doubtless adopted by the ammonites, but not all their architectural creations adopted the same coiled form as the pearly nautilus. Some species of ammonites built their chambered shells in a straight or gently curving line; others even made them elaborately spiralled. But whatever the shape of the completed shell, the method of building it was very much the same.

Although both ammonites and belemnites have really trespassed into this chapter from a later period, there is no doubt that the two types of animals which we must now consider are probably the most typical of all the sea creatures of the Age of Invertebrates. These are the trilobites and eurypterids, both members of the great phylum of the Arthropoda, or 'creatures with jointed feet'. This is the group which later gave rise to the land insects and spiders, and such creatures as the lobsters, centipedes, and scorpions.

During the long millennia of the early Palaeozoic the trilobites were the rulers of the Earth. They dominated the natural scene with the same success as was later achieved by the great reptiles, and is now enjoyed by man himself. But like the reptiles after them, they went in time down the bleak highway to extinction, so that now for more than 200 million years there has been no living survivor of this once powerful race. Fortunately, however, there are abundant fossils to give us evidence of their way of life.

In size and appearance the trilobites could hardly be regarded as well cast as overlords of the Earth. They looked rather like outsize woodlice, but seldom exceeded an inch or two in length. The largest known species measured two feet, but this was a quite exceptional and uncommon form. The name trilobite is derived from the fact that the upper surface of the creature's body, which was covered in a chitinous shell, was divided into three distinct parts or 'lobes' by a pair of clearly marked furrows running from front to back. The body was also divided into three in the other direction, there being a strong shield fore and aft, connected by a middle section known as the thorax. This middle section was divided into segments which would move against one another, enabling the trilobite to roll itself into a ball. This was a most necessary device, for the underside of the body was quite unprotected from possible foes.

Two of the most interesting features of the trilobites were their eyes and their legs. The eyes were often raised and sometimes actually stood right out on stalks, while many species had compound eyes with as many as 15,000 different lenses. The legs ran right down the underside of the body, two to each segment, and there were sometimes over two dozen of such pairs. Each leg was divided into two parts, one for swimming and the other for walking, and a number of spines projecting from their inner sides enabled them to be used as jaws. External jaws of this kind are quite common among the lower animals, and the trilobite fed by crouching on top of its prey, masticating it with its legs, and passing each morsel forward to its mouth.

It is not definitely known what kind of food trilobites ate, and it probably varied from one species to another. Some may have been exclusively predatory, while others probably lived on seaweeds, or scavenged for decaying vegetable matter and carrion. A few kinds are known to have been adapted entirely to a burrowing life, losing the use of their eyes and subsisting on food extracted from the mud of the sea floor.

The vast numbers of fossil trilobites found in the Palaeozoic rocks are often beautifully marked and preserved. In former times, before they were scientifically identified, they were known as petrified butterflies and were much in demand as curios. In some areas of Britain where they are commonly found the quarrymen refer to them as locusts. The hard shells of the trilobites have probably enabled a greater portion of them to survive as fossils than of many of their contemporaries, but even so they were undoubtedly the most common and successful representatives of Palaeozoic life.

The closest rivals of the trilobites were another race of creatures distantly related to them. These were the eurypterids, or sea scorpions, which produced the largest kinds of fossil arthropods in the world, some of which measured nine feet long. The word eurypterid means 'broad-finned', and the oar-like limbs of the eurypterids seem to have been well suited to swimming. Only one species had a tail that could be used at all efficiently as a rudder, so the eurypterids must have steered themselves like scullers by varying the pressure applied by their oar-like limbs to the water. Their anatomy also suggests that they may have swum upside down.

The size, elaborate structure, and great age of the eurypterids make them exceptionally exciting game for the palaeontologist. It would be fair to say that among fossil invertebrates no other creature can be such a thrilling reward to a successful search. There is something infinitely moving in uncovering the fantastic skeleton of one of these great sea scorpions that has been entombed in the Earth's crust for over 300 million years. An evocation of this feeling, and of the emotions associated with all palaeontological research, is given in a passage from the Norwegian palaeontologist, Professor Johan Kiaer, written after the first discovery of the eurypterid known as *Mixopterus* in the Upper Silurian sandstone near Oslo:

'I shall never forget the moment when the first excellently preserved specimen of the new giant eurypterid was found. My workmen had lifted up a large slab, and when they turned it over, we suddenly saw the huge animal, with its marvellously shaped feet, stretched out in natural position. There was something so life-like about it, gleaming darkly in the stone, that we almost expected to see it slowly rise from the bed where it had rested in peace for millions of years and crawl down to the lake that glittered close below us.'

Like the trilobites, the eurypterids failed to survive beyond the end of the Palaeozoic Era. The reasons for this are not definitely known, but it seems likely that none of these great invertebrates of the past was able to compete with the new backboned animals that were shortly to appear on the scene. The Palaeozoic invertebrates had committed themselves too far to a particular kind of specialization, and when their circumstances changed they were unable to adapt. The future of their line was left to their humbler and more insignificant relations, and the main stream of Earth history was entrusted henceforward to a new and more versatile group of performers.

CHAPTER 11

ANIMALS WITH BACKBONES

THE main outline of our story has now brought us to the middle of the Silurian Period, about 330 million years ago. So far we have met only primitive microscopic organisms and invertebrates – creatures which despite their variety and interest will henceforward play a very much less prominent role in the story of life. The actors with whom we shall now be concerned are the vertebrates, or 'animals with backbones', who first appear in large numbers at the end of the Silurian Period, establishing a supremacy which they have ever since maintained.

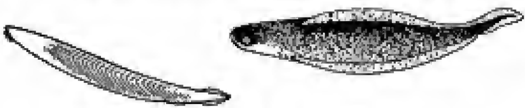
The Silurian Period, as we have said, is named after the ancient Welsh tribe of the Silures who once occupied the area where rocks of this age were first investigated. The man who first studied these rocks, and described some of the earliest vertebrate fossils, was a young nineteenth-century Scottish geologist who later became famous as Sir Roderick Impey Murchison. Murchison was a soldier and served through the Napoleonic wars before retiring to his Scottish estates as a gentleman of leisure. It was not until he was thirty-two that some chance talks with the great British scientist, Sir Humphry Davy, inspired him to acquire a self-made education in geology. The outcome of this was his book *The Silurian System*, published in 1838, which quickly became a geological classic. Murchison was awarded a knighthood and later became Director of the Geological Survey of Great Britain – an astonishing record for a self-taught amateur who knew nothing of geology until he was in his early thirties.

Before describing the early vertebrates from Murchison's Silurian rocks, a word or two must be said about the general development of the backboned animals and their significance in the scheme of later life. Today, everywhere we look, we see the variety and importance of the vertebrates. Man himself is a vertebrate, and so are his domestic animals, the quarry he hunts, and most of the creatures he eats for food. Although outnumbered by the invertebrates by many hundreds to one, the backboned animals have undoubtedly succeeded in dominating the Earth.

To understand the reasons for their supremacy we must remember the overwhelming advantage that vertebrates have in the battle for life. To begin with they possess a strong but flexible internal skeleton, allowing for greater freedom of movement than the cumbersome external shells of the invertebrates. Secondly, the evolution of the characteristic vertebrate skull provides ample space and protection for a well-developed brain, while the backbone itself forms a strong defensive sheath for the nerve cord controlling the animal's movements. Thirdly, the pairing of such important organs as eyes, lungs, kidneys, and so on provides a valuable second line of defence in case of damage or disease. Finally, the grouping of the main sense organs at the front of the head, and the specialization of the limbs and body for locomotion, makes the vertebrate machine altogether more nimble, efficient, and 'aware' than the generally more sluggish and static invertebrates.

Previously, for the sake of simplicity, we have regarded the vertebrates as the thirteenth and last great division of the Animal Kingdom. Zoologically speaking, however, this classification is incorrect. The vertebrates belong, with a handful of other creatures, to a phylum known as the Chordata, or animals with 'notochords'. The notochord, or 'back string', has great significance in vertebrate evolution, being the earliest evidence in the history of life of an embryonic backbone. It consists of a long slim rod of gristly material enclosed in a tough sheath and running from head to tail of the most primitive members of the phylum Chordata. Except in the creature known as *Jamoytius* from the Silurian, it has not been preserved in fossil form, so we cannot give satisfactory examples from the past to show what it is like. But it can be described by analogy, for it is the main support of the body in the modern tunicates or sea squirts, the primitive acorn worms, and above all in the creature known to biologists as *Amphioxus*, the lancelet.

Amphioxus is found somewhat rarely in all the shallow tropical seas of the world. But it is extremely common along the coast of the South China Sea, especially in the Amoy district of the Formosa Straits, where it is collected by the Chinese and sold in large quantities for food. The name *Amphioxus* means 'sharp at both ends' and the creature is shaped like a small, flattened, and semi-transparent cigar. Compared to an ordinary fish it is a very primitive animal indeed. It has no proper fins, no limbs, no jaws, no skeleton, no ears, no eyes (although it may have a general sensitivity to light), and nothing that can properly be called a brain. It moves about by somewhat crude undulations of the body,



Amphioxus (left) and *Jamoytius*

but spends much of its time partly buried in the sand with only its fore part protruding. It feeds in this position by sucking a stream of water into its mouth, from which it strains out microscopic organisms.

Despite this primitive character *Amphioxus* is definitely related to the vertebrates. It has a firm but flexible notochord which not only supports the soft parts of the body but provides a strong axis on which the muscles can pull. A typical vertebrate nerve cord runs along the animal's back behind the notochord – not, as in the invertebrates, along the underside. *Amphioxus* also possesses the fish-like gill slits which, at a higher level of evolution, enable aquatic animals to extract the oxygen they need from the water. In *Amphioxus* these are mainly used as a strainer for food particles.

The notochord, as seen in *Amphioxus*, is undoubtedly the forerunner of the typical backbone of all the higher animals. As evolution progressed this 'back string' became surrounded and finally replaced by the vertebral column, the transitional stage being well represented by the modern eel-like creatures known as lampreys. Lampreys are jawless vertebrates who feed by fixing themselves to the bodies of higher fish and sucking their flesh, but despite their primitive character they possess not only a notochord but the beginnings of a rudimentary vertebral column. Lampreys are more likely to be degenerate vertebrates than a direct link in the evolutionary chain, but they are nevertheless a valuable clue to what our earliest vertebrate predecessors may have been like.

As the backbone invested the rudimentary notochord it combined also with the nerve chord which in creatures like *Amphioxus* ran directly above it. In this way was built up the typical backbone of the higher animals, with its individual bones, or 'vertebrae', its bony projections, or 'spines', which can be easily felt on the backbone of a human being, and the hollow tube, or 'neural canal', which runs through all the vertebrae and contains the main nerve cord. Evidence of this process can be found in spectacular form in the science of embryology. We find there that every vertebrate embryo, including that of man, begins life with a notochord and gradually goes through all the evolutionary stages described above. We can scarcely need further proof that backbones evolved from notochords and that mankind, in common with the other vertebrates, must at some period in the remote past have shared a common ancestor with the sea squirt, the lancelet, and the lamprey.

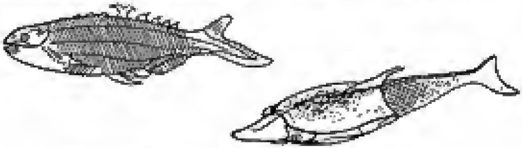
One important problem still remains to be solved, however. What was the origin of the first creature to possess a notochord? If, as it is necessary to suppose, it arose from one of the great invertebrate groups, which group can claim the honour, doubtful as this may sometimes seem, of having given rise to the whole vertebrate phylum, including the human race? Except for the Mollusca, which have never been seriously considered for this role, scientists have at different times ascribed our origin to every other invertebrate group. The most popular choice has been the coelenterates, or jelly-fish, and this in a sense is undeniably correct. In fact, it seems likely from the anatomical evidence that the coelenterates have given rise to every other form of life except the sponges. But between the coelenterates and the vertebrates is it not possible that some more advanced invertebrate group forms an ancestral missing link, or is at least very closely connected to the vertebrate stem? For some time this role was assigned to the annelids, one of the four phyla of worms mentioned in the previous chapter. It was soon realized, however, that to assume that such creatures could evolve a notochord and gill slits would raise more problems than it solved. Another popular choice was the Arthropoda, especially that branch which gave rise to the water scorpions and spiders. But this also had to be abandoned when it was realized that the arthropod's nerve cord was in a position quite inconsistent with vertebrate kinship. Finally scientists turned to what seemed on the face of it to be the most unlikely of all the phyla, the Echinodermata, containing the starfishes and sea urchins. Strangely enough this choice is now generally accepted as correct. Although the adult echinoderms are radically different from vertebrates in every way, their larvae show many points of similarity. This suggests that at some distant period in geological time the echinoderms and the vertebrates may have had a common ancestor. If this is so, then the humble starfishes and sea urchins are our nearest invertebrate cousins – a fact that cannot fail to stimulate in us a number of salutary reflections.

But we must now return from this account of vertebrate ancestry to the ancient Silurian rocks where the first vertebrate fossils were found. The Silurian appears to have been a comparatively mild and agreeable period to live in. The climate was equable and the widespread presence of coral reefs suggests that the seas were warm and shallow. As the Period advanced, however, aridity increased, and the seas retreated to leave great deposits of salt. In the United States especially these Silurian salt deposits are even now very much in evidence, producing in a good year nearly 3,000 million tons of salt, valued at 10 million dollars. Europe during the Silurian was an area of mountain building, and saw especially the formation of a great range, known as the Caledonian Chain, which ran from Ireland to beyond the northernmost tip of Scandinavia. Much of Scotland and the north-west coast of Norway is still composed of the rocks of this Chain, but the middle section has subsided below the North Sea.

In the surviving outcrops of the Caledonian Chain we find the earliest important fossil remains of our vertebrate kinsmen. The only vertebrate fossils to antedate them are some bone fragments from Colorado, suspected as belonging to the late Ordovician Period but too imperfect to be certainly identified. The pioneers of fossil discovery at the British end of the Chain were Sir Roderick Murchison, and his contemporary, the Scottish bank clerk and stone mason Hugh Miller, who achieved great distinction as a geologist and man of letters. On the Scandinavian side the most important Silurian remains were those found near Oslo in Norway in 1909 and fully reported in 1924 by the Norwegian palaeontologist, Professor Johan Kiaer.

These first vertebrate fossils to be found in the British and Norwegian mountains were of course entirely of aquatic animals, and especially of the fantastic primitive fish known as ostracoderms which were to play such a prominent role in middle Palaeozoic life. Ostracoderm literally means 'shell-skinned', and the ostracoderms were largely protected by strong bony armour, which has led to many different varieties being well preserved as fossils. But internally, like our modern lampreys, they lacked any kind of bony skeleton. They had no jaws, and their mouth consisted of a small hole or crosswise slit. Many of them had only one nostril set high up on top of the head, and they were without the typical paired limbs or fins of the true fishes. Their armour covered the whole of the fore part of their bodies, leaving only their tails and the hind part of their trunks free to provide the motive power for swimming. The armour itself was often fantastically shaped, with a pair of rearward-pointing bony projections or horns, which added to the ostracoderms' grotesque appearance.

The group is usually divided into three natural orders. The oldest is that known as the Pteraspida, or Heterostraci, which includes in the famous ostracoderm *Pteraspis* one of the most grotesque creatures of this or any other period. It had an extremely complex system of armour plating and its eyes were set wide apart at the very front extremities of the head. The fore part of its body was very much flattened as if it had been artificially compressed, and, like all ostracoderms, it seems to have lived in freshwater lakes and streams, grubbing about in the mud at the bottom in search of food.



Silurian ostracoderms: *Birkenia* (left) and *Pteraspis*

The second of our three orders, the Cephalaspida, is named after the ostracoderm known as *Cephalaspis*, or 'shield head', so called because of the massive protective plate of bone that covered the fore part of its body. Its fossil remains are commonly found in the late Silurian rocks, and its appearance was compared by Hugh Miller to a saddler's cutting knife 'with a crescent-shaped blade, and the handle fixed transversely in the centre of its concave side'. *Cephalaspis* was a rather larger ostracoderm than *Pteraspis*, but its flattened shape and the fact that its eyes were set in the top of its head suggests that it was likewise a bottom dweller. Some authorities believe that it had the power of repelling its foes by a self-generated electric shock, like the modern catfish and electric eel.

The mud-grubbing habits of the ostracoderms of these two groups does not suggest that they were a particularly active or enterprising lot. With the third order, however, known as the Anaspida, we meet a race of smaller and less heavily armoured creatures who may have ventured away from the bottom into the open waters above. There is evidence for this in their rounded shape and in the placing of the mouth at the front of the head instead of underneath. In fact with *Birkenia*, a typical member of the group, we have a creature who despite the bizarre ridge of hard spines along its back looks not so very unlike some of the common fishes in the sea today.

None of these strange creatures survived the Devonian Period, which came to an end about 275 million years ago. For a long time palaeontologists believed that they were an aberrant side branch of the main vertebrate stem who had made the capital mistake of concentrating on armour instead of motility. But now several authorities regard them as ancestors of the true fishes, having lost their armour by the normal workings of natural selection. Whatever the truth may be, there has certainly been a continual conflict in the history of life between the respective merits of skeletal armour and motility. Usually we find that heavy armour is associated with the more sluggish and static types of life, while small and agile creatures are without it. There can be no doubt which specialization has had the greater survival value, for the small, the swift, and the agile have nearly always succeeded, while the ponderous and slow-moving have generally failed. An apt analogy on this point can be drawn from human warfare. As the military arts have developed, the medieval soldier with his cumbersome armour has given place to the lightly armed, swift moving commando. Likewise, the steel-plated battleship has been superseded by the jet aircraft, which relies almost entirely on its speed and manœuvrability for both attack and escape. These military lessons, hardly learned through the few brief millennia of human history, were clearly written millions of years before in the bones of extinct races, vanquished in that universal battle for life whose progress we are now recording.

But if armour is only a short-term asset, why, we may ask, did the ostracoderms ever become armoured at all? There is no certain answer to this question. The development of armour, like that of shells, may possibly be explained in the first instance by the operation of chemical laws over which the animal has no control. More likely, however, is the view that armour was the first experimental means used by the ostracoderms to protect themselves from the giant eurypterids, or sea scorpions, who shared their environment. Later it was found that concentration on speed and agility was of greater survival value and the armour in successive generations was reduced. This is the way in which the true fishes, with their extreme speed, grace, and agility may have come into being.

Whatever the evolutionary processes involved, by the end of the Silurian Period the animals with backbones were well on the way to domination. The following Period, the Devonian, sees their final triumph and glory, and the differentiation of the vertebrate stock into an infinite variety of forms.

CHAPTER 12

THE AGE OF FISHES

THE Devonian Period, or Age of Fishes, takes its name from the rocks of Devonshire which Sir Roderick Murchison and his colleague, Adam Sedgwick, first investigated in 1836. They were a much mutilated series, however, and nowadays the Devonian rocks of the Rhine valley are regarded as the outstanding examples of these formations in Europe. The opening of the Devonian seems to have been a disturbed time in the history of the Earth. Volcanoes belched fire and lava, and widespread Earth movements threw up many mighty new mountain ranges. Today visitors to Scotland and the English Lake District can still see the huge masses of granite and other igneous rocks that were formed in that distant Devonian Period of 250 million years ago.

The tumult of Earth movements led also to many changes in the distribution of land and sea. For instance, the fossil and geological evidence now shows us that Europe and North America were probably connected by a land bridge stretching from Western Ireland to Newfoundland. This ancient causeway, which geologists have named Eria, has long since foundered beneath the waters of the Atlantic, but a fragment of it may still survive in the shallow bank from which Iceland now rises.

The climate of the Earth at this time seems to have been as warm and equable as it was during the Silurian. In some areas, however, it became increasingly arid, and great belts of sandy desert spread across the world. There were heavy seasonal rains like those now found in the monsoon areas of the tropics, and, as we shall see, these had all-important consequences on the future development of life. In the seas coral reefs continued to flourish and increase, showing that the waters remained warm and fairly shallow. One cup coral, with the imposing name of *Siphonophrentis gigantea*, produced individual buds or corallas three inches in diameter and two feet in length, making it the greatest cup coral of all time.

Among the marine invertebrates nearly all kinds continued at first to flourish despite the growing competition of the fishes. Starfish and other echinoderms were on the increase, while the graceful and gorgeously coloured sea lilies covered the rocks of the ocean bed in gay profusion. Towards the end of the Period the first ammonites appeared, and the little brachiopods, or 'lamp shells', reached the peak of their evolutionary success. Even the trilobites, who in general were on the decline, produced as a last flamboyant gesture the largest representative of their tribe – the mighty *Dalmanites*, measuring nearly two and a half feet in length.

But it is to the new and wonderful varieties of fishes that the Devonian seas really belonged. The primitive ostracoderms were giving place to more active species, some of whom were migrating slowly from the rivers and estuaries towards the open sea. Their newly developed jaws and primitive teeth enabled them to leave the muddy bottom where the ostracoderms used to grub for decaying food debris, and range through the length and depth of the waters seeking living prey. Increasingly their competition threatened the dominion of the giant sea scorpions and trilobites, and soon these ancient invertebrates found themselves fighting a grim and silent battle for survival. This struggle reached its climax during the late Devonian, for by then no invertebrate was a match for the swiftly evolving and highly adaptable fish. By the close of the Period the sea scorpions and trilobites were well on the road to extinction.

The new vertebrate rulers of the seas quickly developed by a sudden outburst of explosive evolution into a multitude of different forms. Their exact ancestry is still disputed, but they must have originated in a group of animals not unlike their ostracoderm predecessors. The earliest and most primitive group were the Placodermi, or 'plated skins', the first vertebrates to possess rudimentary jaws. Next came the Chondrichthyes, or 'gristly fishes', whose jaws showed a considerable advance on the placoderms but who lacked a true bony skeleton. And finally there were the Osteichthyes, or 'bony fishes', who were the ancestors of most of the fish types living today.

Of all this great variety of Devonian fishes the ancient placoderms are those who most powerfully affect our imagination. This group is divided into four natural orders, of which the three best known all begin with the same initial letter, and for once are quite easy to pronounce: the Acanthodii, the Antiarchi, and the Arthrodira. The fourth order, which has been more recently investigated, has been named the Stegoselachii, and its members look like armoured caricatures of our modern skates and rays.

The acanthodians, who are the most primitive of the placoderms, are sometimes referred to as 'spiny sharks' because their fins consist of a web of skin supported at the front by a stiff spine. There were two of these fins one behind the other on the back, and two pairs of fins, one fore and one aft, on the underside of the body. Thus the acanthodians foreshadowed the typical fin arrangement of modern fishes, although often, as in the genera called *Climatius* and *Euthacanthus*, they had several additional pairs of small spiny fins between the two main pairs underneath. In other acanthodians, such as *Parexus*, the dorsal spine grew to about half the length of the creature's body, so that its owner must have found it more of an embarrassment than an advantage. Despite their popular name of 'spiny shark' the acanthodians were not closely related to the true sharks, which we shall be describing later in this chapter. Nor did they often grow to more than a few inches in length. Like the ostracoderms, they were exclusively freshwater fish, never venturing far down the estuaries towards the open sea.

Sharing the Devonian lakes and rivers with the acanthodians were the representatives of the second placoderm order, the antiarchs, who likewise never grew to any great size. These were so grotesque and elaborately specialized that early palaeontologists were at a loss to know how to classify them. In that geological classic, *The Old Red Sandstone*, published in 1841, Hugh Miller devotes nearly a chapter to his discovery of one of the most famous of the antiarchs known as *Pterichthys*, or *Pterichthyodes*. This was a small creature between six and twelve inches long, the forepart of its body encased in bony armour, flattened underneath and rising on top to a pronounced peak. Its eyes were placed on top of its head and between them was a third, or pineal, eye – an organ commonly found in the lower vertebrates. Two bone-plated limbs like the legs of a crustacean projected on either side, and the body was covered with a fantastic armoured shell, a fact which led Miller to remark: 'My first formed idea regarding it was that I had discovered a connecting link between the tortoise and the fish.' But he soon recognized his error and went on to give an accurate and incidentally most charming and readable description of the creature's appearance and characteristics. Even so he cannot resist one of his favourite jibes at the evolutionary theories of Lamarck: 'Had Lamarck been the discoverer', he says, 'he would unquestionably have held that he had caught a fish almost in the act of wishing itself into a bird.'

The placoderms we have been describing so far have all been small freshwater forms, but with the arthrodires, or 'joint necks', we come to an order which includes the first of the vertebrate giants of the seas. These were less heavily armoured than the antiarchs and some of their bony plating was covered with skin in a similar manner to a human skull. Their name derives from the complicated peg and socket joint which connected their head and back, enabling the head to be moved up and down but not from side to side. They also had a fixed lower jaw, which meant that the head itself had to be raised and lowered to grasp the prey. This is, of course, an exactly opposite arrangement to that found in all species of the higher animals.

Some of the arthrodires, such as *Coccosteus* from the Devonian rocks of Scotland and Germany, were only about two feet in length, but the order also included some of the greatest ocean carnivores of all time. We owe much of our knowledge of the giant Devonian arthrodires to the generosity of a group of American business men who subscribed for a mechanical excavator to dig the fossils from the centre of Cleveland City, Ohio. The most spectacular specimens were between twenty and thirty feet long, and were assigned to a genus with the name of *Dinichthys*, meaning 'terrible' or 'huge' fish. One incomplete fossil, which was christened *Titanichthys*, was estimated to have been even bigger in life than *Dinichthys*, with a possible length of over forty feet. The skulls of these great arthrodires, which often measured over a yard long, were equipped with jagged projections on the jaws which served as primitive teeth. No other occupant of the sea could rival them in speed, strength, or material equipment, and they were very much more prominent during this Period than any other type of fish. Yet they must have specialized in qualities that did not in the long run make for survival, for after a meteoric rise and fall they disappear for ever from the geological record.

Although the arthrodires were one of the first groups of fish to move from the fresh or brackish water of the estuaries towards the open sea, they were not alone in their enterprising adventure. Both the Chondrichthyes, or 'gristly fishes', and the Osteichthyes, or 'bony fishes', which we mentioned earlier in this chapter, were well represented in the Devonian seas. Many examples of the gristly fishes have survived into modern times, and include such familiar species as the sharks, skates, and rays, as well as such strange deep-sea fish as the chimaera, or ratfish, and its various related forms. But the bony fishes have been even more successful. Today every single freshwater fish belongs to this class, in addition to the vast majority of sea fishes, comprising over 20,000 species.

Cartilage is not easily preserved in a fossil state and therefore remains of the gristly fishes are few and far between. However, in the same Cleveland shale of Ohio where *Dinichthys* was found, there are examples of the small Devonian shark *Cladoselache*. In many cases preservation has been exceptionally good, so that the body outline can be distinguished, and even some details of the soft parts such as muscles and kidneys. *Cladoselache* was an ocean-dwelling form, but another Devonian shark called *Pleuracanthus*, had returned to the ancestral fresh waters of the lakes and rivers. It had a torpedo-shaped body between two and three feet long, and behind its head there grew a long spine which was sometimes over a third of the length of its body. No one knows exactly what this spine was for, but one of the fascinations of palaeontology, as of natural history in general, is that it poses so many intriguing problems of this kind. A possible explanation is that the spine acted as a breakwater for the exceptionally long dorsal fin.

In Devonian times the arthrodires and the more powerful of the gristly fishes were the dominant races on the Earth, but they were soon to be dethroned by the great class of the Osteichthyes, or 'bony fishes', who still rule over the oceans of today. The kingdom of the bony fishes has two main divisions of which the most important is now the group known as the ray-finned fish or, to be more technical, the Actinopterygii. These fish are also loosely termed ganoids, or 'bright scaled fish', and include not only such primitive extinct forms as the palaeniscoids of the late Palaeozoic, but a huge group known as the teleosts which contains nearly the whole range of modern fish.

But the reader who is less interested in the fish themselves than in the main line of human ancestry can forget the minutae of ganoid classification and concentrate instead on the other much smaller group of bony fishes known as the Choanichthyes, or 'fishes with internal nostrils'. Although today, by comparison with the ganoids, these are an insignificant and undiversified group, their Devonian forebears played such an overwhelmingly important part in our story that we cannot afford to dismiss them lightly.

The distinguishing feature of the Choanichthyes was that, in addition to the gill slits by which fishes normally extract oxygen from the water, they also had a pair of well-developed internal cavities, or lungs. Actually this in itself was not particularly unusual; lung-like structures existed in many other kinds of fishes, and were used as gas-filled buoyancy chambers to enable their owners to rise and fall in the water. But what was unique and unprecedented about the lungs of the Choanichthyes was that they were adapted to function in the same way as the lungs of land animals. In other words, the Choanichthyes could take in the oxygen they needed directly from the air.

Why, we may ask, was this special adaptation necessary, and how did it come about? The answer may well lie in the nature of the Devonian climate, which we have already described as of great aridity, broken by heavy seasonal rains. As a result many shallow lakes and streams were in high flood for several months of the years and then as rapidly dried up, leaving their unfortunate inmates stranded on the sandy bottom. The survival value of an air-breathing mechanism in such circumstances can be easily understood and was almost certainly the reason why the Choanichthyes developed one.

This view is supported by the branch of the group which survives to the present day – the Dipnoi, or lungfish. There are three genera of lung fish that are especially well known, found respectively in Australia, South America, and the Nile Valley. They inhabit swamps and marshes in regions of seasonal drought, and when these dry up, the American and African species simply retire to a mud cocoon and breathe air until the coming of the next rains. The Australian lungfish is less versatile, but is nevertheless able to surface and take air directly into its lungs.

But the air-breathing fish that principally concern us here are not the Dipnoi, but an early branch of the Choanichthyes known as the Crossopterygii, or 'fringe-fins'. This branch of the group was thought until recently to have been extinct for well over 60 million years. It was therefore with excited astonishment that the scientific world learned in 1939 of the capture off South Africa of a coelacanth, one of the original crossopterygian fish. Unfortunately only the skin was preserved, but several further catches made since the end of 1952 have enabled the complete anatomy of this strange creature to be fully investigated.

By a study of the lungfish, the coelacanth, and the fossil remains of other early crossopterygians, we have now been able to learn a great deal about the anatomy of this primitive group, as well as the workings of the air-breathing mechanism. In the crossopterygians particularly we find that the arrangement of the paired fins is well adapted to a type of four-limbed progression. The internal skeleton is projected into four fleshy lobes which form the basis of the fringed fins, an arrangement which obviously foreshadows the development of four-legged land animals. Moreover, the lobes are controlled by strong muscles, which suggests that even when the earliest crossopterygians were strictly aquatic the fins may have been used for crawling along the muddy bottom.

There, is of course, no suggestion that such a specialized creature as the coelacanth could be a direct ancestor of the land vertebrates. Even less possible is an ancestral relationship with the lungfish. Such primitive air-breathing species had already set forth in their early history on evolutionary lines of their own. But what is now certain – and will be developed at greater length in the next chapter – is that somewhere in this almost extinct group of the Choanichthyes must be found our own ancestors. The lungfish and the coelacanth may not be in the direct parental line, but they have at least a very good title to be numbered among our earliest aquatic uncles and aunts.

CHAPTER 13

THE GREAT INVASION

THE stage is now set for one of the most momentous events in the drama of life – the invasion of the land by the strange early creatures of the sea. For long ages – far longer than any human mind could attempt to imagine – the Earth's landscape had been a barren wilderness of rock and stones. The vast silence was broken only by the whistling of the wind among the mountains, the staccato rattle of raindrops, and the hiss of great rivers rushing headlong towards the sea. Occasionally the menacing mutter of a volcano would swell into the crescendo of an eruption, or the ground would tremble as an earthquake sent deep cracks and fissures snaking across the barren plains. But there were no trees to sway and rustle in the breeze, no insects humming drowsily under the summer sun, no single song or call of beast or bird to break the uneasy stillness of that lifeless land.

But at last, slowly and almost imperceptibly, the Great Invasion began. The waves lapping the rocks, and thudding monotonously on the barren beaches, left a green scum at the meeting place of sea and land. Tiny relations of the trilobites and sea scorpions, stranded on sandbanks or muddy deltas, slowly learnt the first adaptations necessary for an air-breathing existence. Many were dried up and killed by the rays of the sun, while others were washed back by the waves or tides to their native element, but with the passing of the ages a few of these unknowing pioneers managed to establish a precarious bridgehead on the fringes of the primeval seas. The first lichens and mosses took root in the damp crevices of the rocks; primitive land plants pressed forward up the beaches and spread over the desert plains; creeping and crawling things scurried and writhed in the marshes and then slowly advanced from the mudflats of the tropical estuaries to the virgin forests of the interior. And at last, somewhere on the Earth, a primitive air-breathing fish forsook its ancient home and set out to dare in this strange new land a vast and unpredictable future.

Not unnaturally it is these first vertebrate land dwellers who mainly capture our imagination and who will play the leading roles in the remainder of our story. But we must always remember that their advance from the sea to the land was only made possible by the earlier landward movement of the plants. For this reason, before continuing, we will briefly recapitulate the main stages of plant development, and also say a word or two about the first air-breathing invertebrates who made an independent conquest of the land at about the same time as our own ancestors.

Our last mention of the Vegetable Kingdom was in Chapter 9, when we spoke of the plant-like bacteria and the great natural division of the Protophyta, or 'first plants'. We particularly stressed there the importance of the Algae, of which there are over 1,800 different species, and which include the plants familiarly known to all of us as the ocean seaweeds. There is amazing variety between the members of this group, which range from microscopic freshwater forms to gigantic seaweeds measuring between 100 and 200 feet long. Some of the smaller Algae, such as the diatoms commonly found in the surface-floating plankton of the seas, secrete membranes of silica which are preserved in drifts on the ocean floors. Others have adapted themselves to life in such extraordinary environments as the snows of high mountains and the poles, or the waters of hot springs. For example the Algae found in the hot springs of the Yellowstone National Park in the United States live and breed quite happily at an average temperature of 187° F., only 25° F. below the boiling point of water. At the other end of the scale are the great ocean seaweeds known as the Laminariales, or oarweeds, These include such giant forms as the fifty-foot *Nereocystis* of the North Pacific, and the mighty *Macrocystis* of the southern seas, which sometimes exceeds a length of 180 feet.

All these Algae belong to the more primitive of the two great subdivisions of the Vegetable Kingdom, which comprises what are technically known as the 'non-vascular' plants. Plants of this type have no true leaves, stems, or roots, and are without a well-developed internal mechanism for conducting food and water. They are thus restricted mainly to an aquatic environment and the majority actually spend their whole lives totally submerged under water. Many others, such as the seaweeds growing on rocks and breakwaters, are covered intermittently by the tides, while even the land forms, such as the fungi, liverworts, and mosses, cannot exist except in reasonably moist surroundings.

It was these simple kinds of plants that in the early years of the Silurian Period made their first tentative advance up the Earth's inhospitable shores. Before long the rocks of the sea coast and the marshy fringes of the estuaries were carpeted with the first kinds of moss and lichen. For the first time since the cooling of the Earth's crust, the land began to take on a colour that was not a property of its own rocks and minerals but was added to it by the agency of living things.

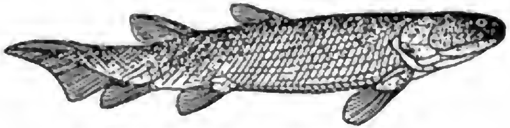
But the non-vascular plants were obviously unsuited and inadequate to the demands of a full-scale invasion of the land. As a result, throughout the Silurian and early Devonian Period, a more elaborate type of plant life developed which could survive away from the seas and rivers, and did not demand a perpetually moisture-laden atmosphere. These new kinds of plants had long roots that could suck moisture from deep in the ground, and comparatively rigid skeletons that would hold them erect so that they could bathe in the life-giving rays of the sun. Their stems were either hollow or fitted with an internal network of tubes, so that water could be conducted to any part of them at will.

By the middle of the Devonian Period these 'vascular' plants, as they are called, were widely established in many of the land areas of the world. Some were unadventurous and clung timorously to the borders of the lakes and rivers, but others, better adapted and more enterprising, advanced across the empty plains and up the lower foothills of the mountain ranges to form the Earth's first forests. The trees and plants of these forests, although widely differentiated in shape and size, were all entirely unlike the typical plants that live today. None had true leaves nor any kind of flower, and the landscape must have been a subtly coloured Whistlerian symphony in varying shades of green. The most advanced kinds of plants were the ferns and tree ferns, some of which had already adopted the modern form of reproduction by means of seeds. For the rest, there were some odd smooth-stemmed plants with needle-like spines, a few primitive horsetails, and a variety of trees known as lycopods, which were covered with a growth of overlapping leaf-like 'scales'. The name lycopod comes from two Greek words meaning 'wolf foot', because of the claw-like shape of the roots, and members of the group are also popularly referred to as 'scale trees'. Some of these primitive Devonian trees have left fossilized stumps more than three feet across, while the tallest of the lycopods, dignified by the imposing name of *Protolepidodendron primaevum*, or 'first primeval scale tree', grew to a height of over forty feet.

On to this new stage, with its backcloth of green vegetation, there slowly advanced the invertebrate spearhead of the Great Invasion. Quite early in the Devonian Period, soon after the land plants had become firmly established, several kinds of marine invertebrates were accustoming themselves to a partly terrestrial life in the intertidal beaches; then the inevitable step was taken and they became truly air-breathing forms. There were mites and millipedes and wingless insects, and creatures like woodlice who may have been related to the trilobites. Small scorpions, seldom more than an inch or two long, lived on the sandy shores, and another group of arthropods developed into the earliest land spiders. By the end of the Devonian, the primeval forests were teeming with these tiny life forms, the ancestors of the strange insects and other land invertebrates who were shortly to come into their own.

Only one group was now missing from this opening act in the drama of land life – the group of vertebrate air-breathing fish whose ranks contain the forebears of all the principal actors in the cast. As we said in the last chapter, neither the lungfish nor such a specialized crossopterygian as the coelacanth can be qualified for this ancestral role, but there are several other crossopterygians who may be nearer the main line of descent. For instance, the primitive *Osteolepis* shows many of the anatomical characteristics that were later developed by the first land dwellers, while even the more highly developed *Eusthenopteron*, which could flounder about on the shore with its muscular fin lobes, seems significantly near the main evolutionary stream.

In any case, a variety of air-breathing creatures of this kind were not slow in making their appearance, and well before the Devonian Period gave place to the succeeding Age of the Coal Forests they were scuttling along the



The Devonian crossopterygian *Osteolepis*

beaches and mud-flats, and perhaps making brief forays after food into the neighbouring undergrowth. As the millennia went by, they established themselves in increasing numbers and variety along the world's coastlines. It was a slow process of infiltration rather than a mass invasion, and was as devastatingly effective as such methods often are. Before long the descendants of this enterprising and adaptable fifth column of the sea had entrenched themselves on land in a position of impregnable strength.

With the primitive crossopterygians we take leave of the last group of creatures who can definitely be assigned to the great natural class of the fishes. We must now turn to the important group of creatures which occupy an intermediate position between the crossopterygians and the first of the true land-living animals. These transitional forms, belonging neither wholly to the land nor to the water, are placed together in the natural class of the Amphibia, which is still represented by several creatures that exist today. Frogs, toads, newts, caecilians, and salamanders are all living amphibians – the last descendants of a group who at the time of the Great Invasion were the most important creatures on the Earth, and from whom all other land vertebrates have since been derived.

The main characteristic of the amphibians is that, although they can breathe air and are partially adapted to life on land, they must in general return to the water to breed. The typical amphibian life-cycle can still be studied in the common frog. As everyone knows, the frog lays its eggs in the water and in due course these hatch into the fish-like tadpoles. As the tadpoles grow, their gills disappear and their lungs and limbs quickly develop into those of land-dwelling animals. Soon the newly formed frog leaves its aquatic environment and ventures out into the damp grasses and rushes of the shore. But it cannot make a complete break with the water, for sooner or later it must return there to breed.

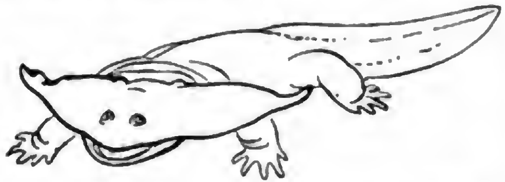
The early amphibians obeyed the same laws as the modern frog, and it was only very gradually that their successors learnt to adapt themselves completely to land life. In a later chapter we shall briefly describe how this occurred; here meanwhile we must glance at some of the first amphibians to pioneer the invasion of the land. The most primitive of these creatures were known as stegocephalians, or 'roofed-heads', because of the heavily boned head structure they had inherited from their crossopterygian forebears. The word is a general term, however, not used by palaeontologists as a guide to classification. The natural divisions of the amphibians are mainly determined not by the head structure but by a number of differences in the vertebra of the backbone. These differences are only of interest to anatomical specialists, and for our purpose it will suffice to describe a few of the early amphibian types.

The most famous of these creatures were those known as the labyrinthodonts, a word which means 'labyrinthine toothed' and which derives from the peculiarly constructed inward folding of the tooth enamel. This contorted tooth structure, incidentally, was already apparent in such primitive crossopterygians as *Osteolepis*, a fact which confirms the main line of amphibian descent. The labyrinthodonts flourished from late in the Devonian right on into the Triassic Period of the succeeding Age, a span of at least 100 million years. During this time they took on a multitude of different forms, ranging from a few inches in length to ten or more feet. Many of them retained the elongated body of the typical fish, and a flattened tail that was useful in swimming. Modern amphibians still show evidence of this same aquatic ancestry. The salamander, for example, even when supported by its legs on dry ground, progresses with the sinuous s-shaped twists of the body that characterize the fishes.

The smaller labyrinthodonts seem to have been the most successful in establishing a satisfactory life away from the water's edge. In early large types, such as the fifteen-foot monster known as *Eogyrinus*, the limbs were primitive and largely undeveloped, showing that it never travelled far from its ancestral home. This is really not surprising, for once the support of water had been removed, the possession of mere bulk would have become a handicap rather than an an advantage. As is demonstrated so often in the history of life, it is the small and active animals who are the most adaptable and lead the way in exploring new environments.

Among the labyrinthodonts the most successful early form was the little creature known as *Diplovertebron*, which was only two feet long. The shape of its body and its thick wedge-shaped tail remind us of a small modern crocodile, and its strong, well-developed limbs were well suited for making fairly lengthy forays on land. Nevertheless it probably fed mainly on the small palaeoniscoid fish who lived in the Carboniferous rivers.

Gradually the adaptations made by the labyrinthodonts to land life became more and more successful until, with the American genus *Eryops*, we find a creature who spent most of its time on land and only returned to the water to breed. *Eryops* was found in geological formations in Texas and was of different proportions to its more fish-like predecessors. It measured about five feet long, and was very thickset and stocky, with short but powerfully developed limbs. Despite its comparatively successful career on land, its legs were still of the sprawling type that characterized all the early amphibians. The upper parts stuck out horizontally from the body with the lower parts pointing downwards at right angles, an arrangement that must have given *Eryops* a somewhat clumsy gait. This was bettered by its smaller relation known as *Cacops*, who developed proportionately longer legs and a



Diplocaulus, an extraordinary amphibian from the Lower Permian of North America

shorter tail; but none of the amphibians ever achieved the agility of the more advanced forms of life.

The labyrinthodonts were the most important of the early pioneers of land life, but their advance was shared by a number of other amphibians of even more extraordinary appearance. To take only one example, it is impossible to look at a reconstruction of the little amphibian known as *Diplocaulus* without beginning to doubt the evidence of one's senses. Here, in the smallest space – for *Diplocaulus* was only two feet long – is one of the most grotesque creatures that Nature ever produced in the catalogue of life. Its body and skull were broad and flat, its legs disproportionately short, and its eyes set close together on the upper surface of its head. The skull itself was extended backward on either side by a pair of bony projections or 'horns', which gave it the appearance of a modern tailless aircraft, or a boomerang very much broadened in the middle. So bizarre and extravagant was the creature's anatomy that we can be sure that it was an overspecialized and degenerate form – a bad evolutionary joke, living without hope of readapting itself to the main stream of progress.

But not all the contemporaries of the labyrinthodonts were as extraordinary as *Diplocaulus*. For instance, a little five-inch amphibian known as *Microbrachis* looked superficially like a scale model of a large early labyrinthodont. It belonged to a group of creatures known as the microsaurs, or 'little reptiles', who despite their name had far greater affinities with the amphibians than the reptiles. There were also long snake-like creatures such as the three-foot *Ophiderpeton*, or the little *Sauropleura*, barely seven inches long. These creatures were related both to *Diplocaulus* and the microsaurs, but had either lost the legs they originally possessed, or preserved them only as vestigial structures.

Despite the profusion and variety of the early amphibians, we must realize when we look today at their insignificant descendants that they are a vanquished race. Certainly they were the first creatures to attempt life on the land, with all its strangeness and unknown possibilities; and they were also a vital and indispensable link between the creatures of the sea and the land. But they failed to take the ultimate risk, to make the final adaptation, that would have emancipated them for ever from their aquatic environment.

Yet somewhere among them, among those countless millions of forgotten creatures who scurried through the undergrowth of the world's primeval forests, there must have been one who handed on the flame of vertebrate life to the great all-conquering reptiles who were to come, for life is a continuous process and the vitality of future races is born at some stage out of the failures of the past. In the next chapter we shall deal at more length with this subject. We shall try to paint a picture of the great Age of the Coal Forests, and the period of crisis and catastrophe that succeeded it. When the dust and tumult of this climax in Earth history have died away, we shall find that but for the early amphibian pioneers the torch of life would never have shone so brightly into the future.

CHAPTER 14

THE AGE OF THE COAL FORESTS

THE time in Earth history when the amphibians were adapting themselves for the first time to life on land is known to European geologists as the Carboniferous Period. It is divided into two parts, a Lower Carboniferous lasting for about 20 million years, and an Upper Carboniferous lasting for about 35 million years. In America the practice is somewhat different, the Lower Carboniferous being called the Mississippian Period, and the Upper the Pennsylvanian, after the rock formations found in those States. The word Carboniferous comes from the Latin word 'carbo', meaning coal, and the later, or Upper, of the two Periods, which began about 255 million years ago, is important for being the time when about half the workable coal measures of the world were laid down.

Coal is a rock-like fossil fuel formed by Earth pressure from ancient deposits of decaying vegetation. The modern form of these deposits can be seen in the familiar peat bogs of Britain, and more especially of Ireland, where soil is naturally mingled with the remains of moss and reeds to form a soft and spongy carpet. Some of these bogs are forty or fifty feet deep, and the peat, when dried, can already be used as a smokeless if rather inefficient form of fuel.

The formation of peat requires considerable moisture and an adequate supply of vegetation. Its value as fuel varies not only with the conditions under which it is laid down but also with the type of vegetation composing it. The same thing applies to all those ancient deposits of peat which have been hardened into coal. Such coal measures have been formed at several periods during the Earth's history, but in none have the requirements for a first-quality fuel been so generally and ideally fulfilled as in the primeval forests of the Upper Carboniferous Period.

It seems that the climate at that time was becoming steadily warmer and moister. We can tell this not only by the presence of the coal measures themselves but from the fossil remains of animals and plants that are associated with them. The plant imprints found in the coalfields tell of a luxuriant vegetation such as the world had never hitherto known. Students of fossil plants – or palaeobotanists as they are called – can tell from the texture of many of these leaves that they must have grown in exceptionally warm and humid conditions. The warmth of the climate is also proved by the presence in high latitudes of the fossil remains of corals and other tropical animals of the period. For example, in the icebound island of Spitzbergen in latitude 78° N., it is still possible to see massive coral reefs dating from this great Carboniferous summer of long ago.

Apart from the climate the geographical conditions of the Carboniferous Period were ideal for the formation of the coal measures. In the northern hemisphere, where most of the world's coal is now found, Earth movements were raising former sea beds into flat, swampy plains. These were perfect sites for the growth of the coal forests and soon many thousands of square miles were covered with trees and dense undergrowth. The swamp waters protected the dead or fallen plants from immediate decay, and layer upon layer of vegetation turned slowly into thick beds of peat. Buried under later sediments these gradually became metamorphosed into the rich coal seams of today.

The process by which peat is turned into coal makes a fascinating study, but is still imperfectly understood. The principle, briefly, is the elimination of the hydrogen and oxygen in the decayed matter so that its carbon content is proportionately increased. Biochemical action by fungi and bacteria plays a large part in this change, as does the heat and pressure set up by the accumulation of new sediments. There are so many factors governing the formation of different coal measures, even if they are of the same period, that it is not surprising that the final product varies so much in type and quality.

The astonishing richness of the Carboniferous coal fields is perhaps more apparent in America than anywhere else in the world. The United States is the largest single coal-producing country, with an annual output approaching 600 millions tons. In the Upper Carboniferous anthracite fields of eastern Pennsylvania the seams are often forty feet thick, and an annual output of over 80 million tons has been kept up for more than twenty-five years. The workable seams of western Pennsylvania, Virginia, and Ohio occupy 6,000 square miles and are estimated to contain no less than 22,000 million tons of coal. The yield of the mines in this area has a value of more than twenty times that of the output of the greatest gold mine in the United States.

Enough has now been said to show the immense interest and importance of the Carboniferous coal measures. We must next turn to the vast swamp forests from which they were formed, and try to evoke the atmosphere of that ancient landscape, with its strange trees and plants, and multitudinous animal life.

The vegetation of the Carboniferous Period was a direct development of that of the Devonian, which we described in the last chapter. Many of the plants were still what botanists term 'spore-bearers'. This name refers to their method of reproduction by the tiny bodies known as spores, which are cast loose by the parent plant to grow as best they can. But there were also now increasing numbers of seed-bearing plants. These are a far more specialized form than the spore-bearers, preserving the reproductive cell on the plant until the embryo has reached quite an advanced state. All our typical modern flowering plants are seed-bearers, whereas the more primitive ferns preserve the old method of reproduction by means of spores.

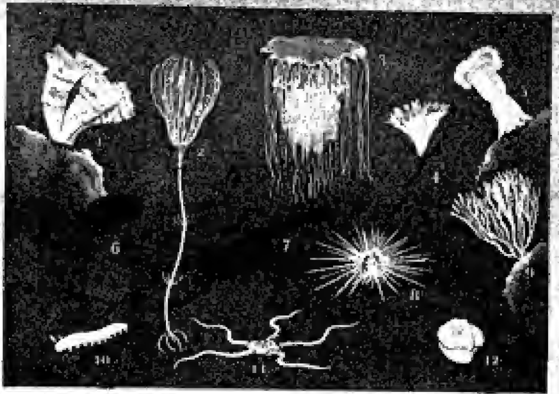
The giants of the Carboniferous Period were still the lycopods, or scale trees. These were divided into two main types, Lepidodendron and Sigillaria, many of which grew to even greater size than their famous Devonian predecessor, *Protolepidodendron primaevum*. The typical Lepidodendron of the Carboniferous Period grew to a height of over 100 feet.

The lower part of the trunk was straight and slender, often for well over three-quarters of its length, and then divided into a fantastic array of branches like a candelabra. Fossil remains of one British species have been found that probably exceeded 130 feet in height.

All species of Lepidodendron were covered with the typical overlapping scale-like leaves which give the lycopods their popular name. The leaves themselves have seldom been preserved, but their shape and structure is known from fossilized imprints. When they decayed they left behind a pattern of scars on the trunk which are a great help to palaeobotanists in identifying Lepidodendron fossils. The pattern is always arranged in a steep spiral and is as neat and regular as a man-made mosaic.

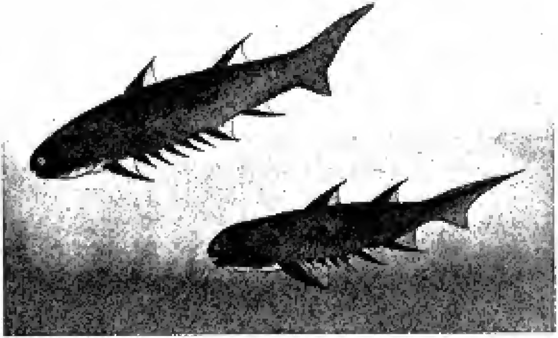
The other type of lycopod, Sigillaria, had a broader trunk than Lepidodendron, but it was less commonly branched. The name comes from the Latin 'sigillum', meaning a seal, and was given to the tree because of the fantastic appearance of the leaf scars. Each of these so closely resembles the imprint of a seal that it is difficult to realize that it is not artificially produced. The leaves themselves covered the whole trunk, but grew longer and more imposing towards the top. The largest leaf specimen of all, deduced from the fossil evidence to exceed three feet, belonged to a species with the suitably impressive name of *Sigillariophyllum lepidodendrifolium*.

Apart from the lycopods, the most remarkable trees of the swamp forests were the Cordaites, named after the nineteenth-century Bohemian palaeontologist August Joseph Corda. These were the forerunners of our own coniferous firs and pines but differed from them in several important ways. For instance, their seeds were spread out at intervals along a stem instead of being concentrated in cones, and their leaves were strap-like instead of the typical needle shape of modern conifers. The Cordaites were tall and graceful trees. Some specimens grew to a height of 120 feet or more, and had trunks over three feet in diameter. The wood resembled that of a modern pine, but the trunk was bare of branches for

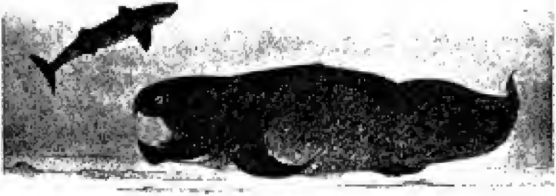


1a. Animals of the Age of Invertebrates. 1, Coral. 2, Sea lily. 3, Jelly-fish. 4, Graptolite. 5, Sea anemone. 6, Trilobite. 7, Sea scorpion. 8, Sea urchin. 9, Sponge. 10, Worm-insect. 11, Starfish. 12, Brachiopod.

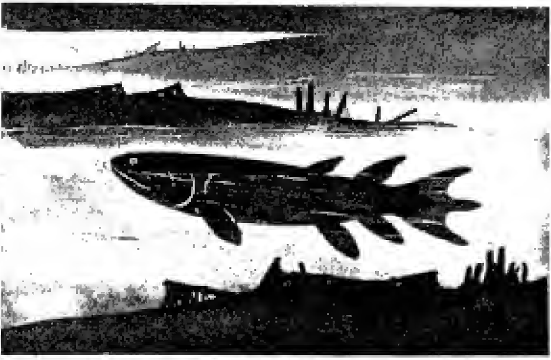
1b. Body of the gigantic cephalopod *Endoceras proteiforme*, washed up on a Palaeozoic shore.



2a. Typical freshwater placoderms: *Euthacanthus* (above) and *Climatius*.



2b. The giant arthrodire *Dinichthys* pursuing the Devonian shark *Cladoselache*.



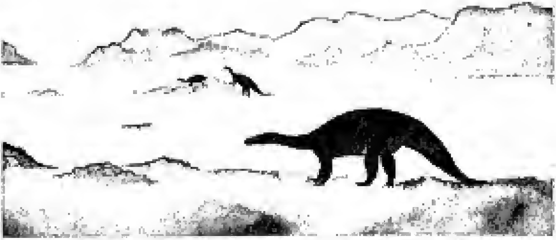
3a. *Eusthenopteron*, an air-breathing crossopterygian fish of the Devonian Period.

3b. A primitive amphibian on the shores of a Devonian estuary.

4. A labyrinthodont in a typical swamp of the Age of the Coal Forests.

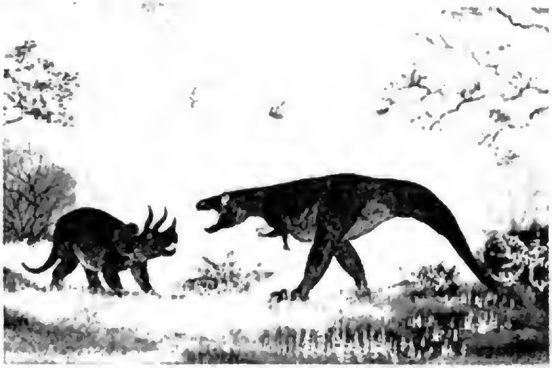
5a. Two fin-backed reptiles from the Permian of Texas: *Dimetrodon* (left) and *Edaphosaurus*.

5b. Mammal-like reptiles of the Lower Triassic of South Africa: *Kannemeyeria* (background) and *Cynognathus*.



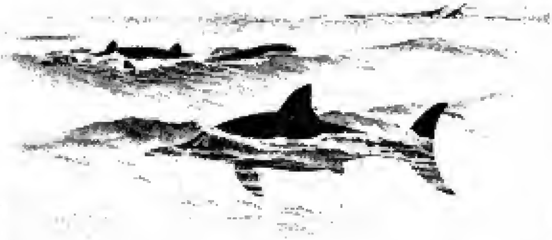
6a. Plateosaurs crossing the German deserts of the Triassic Period.

6b. The forty-ton sauropod dinosaur *Brontosaurus*.

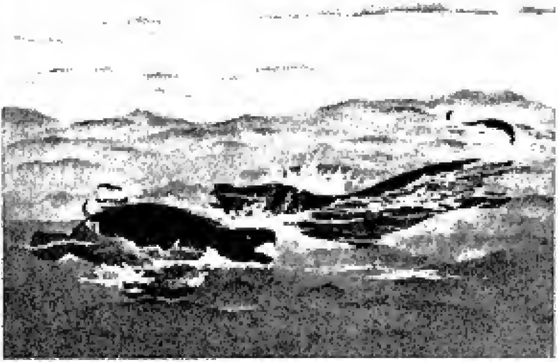


7a. *Tyrannosaurus rex*, greatest of the carnivorous dinosaurs, attacking *Triceratops*.

7b. The duck-billed dinosaur *Anatosaurus*.



8a. An ichthyosaur (foreground) and a plesiosaur – typical reptiles of the Mesozoic seas.

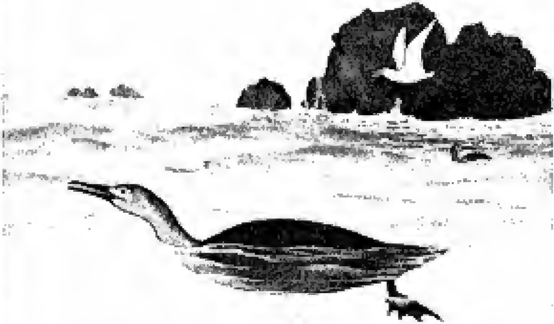


8b. A mosasaur attacking *Archelon*, a giant turtle of the Cretaceous Period.

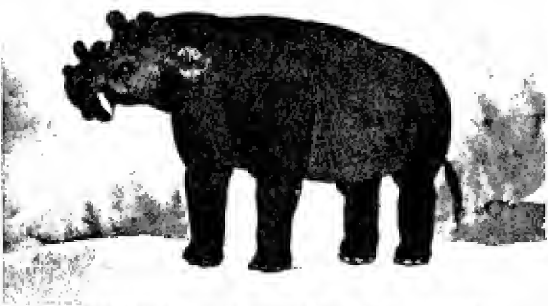
9a. *Rhamphorhynchus* (centre) and three other pterosaurs.

9b. The giant pterosaur *Pteranodon*.

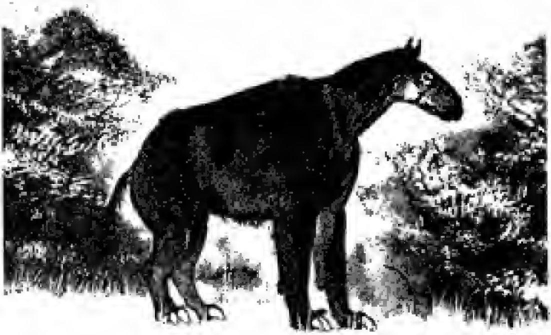
10a. *Archaeopteryx*, the first bird.



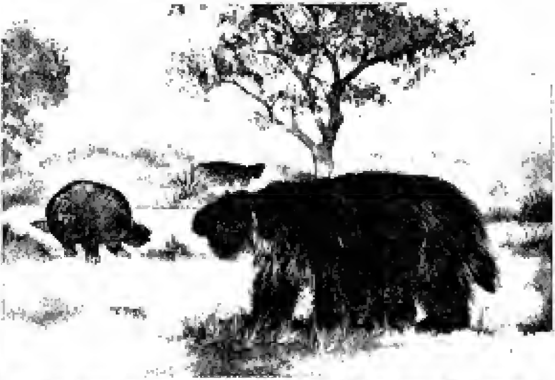
10b. *Hesperornis* and (flying in the background) *Ichthyornis*.



11a. *Uintatherium*, a grotesque mammal of the early Tertiary Period.



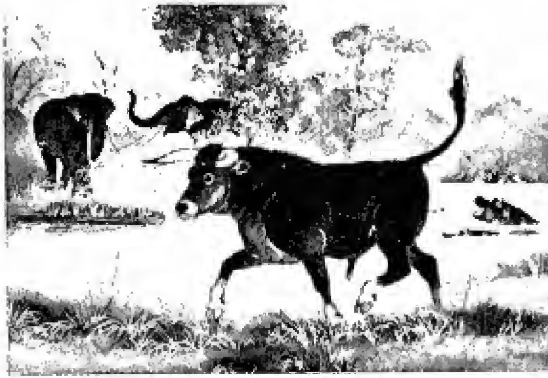
11b. *Moropus*, a chalicothere.



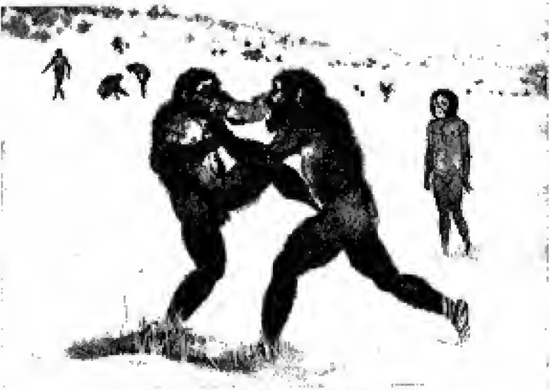
12a. The giant ground sloth *Megatherium* and (left background) *Glyptodon*, a giant armadillo.

12b. The sabre-toothed cat *Smilodon* with the carcase of a young mastodon.

13a. Mammals of the Pleistocene snows: woolly mammoth, woolly rhinoceros, and wolves.



13b. Mammals of the Interglacial Periods: *Elephas antiquus* (left background), the aurochs (centre), and a hippopotamus.



14a. Australopithecines fighting.

14b. Pekin man cooking at an open air hearth.

15. Neanderthal man, an extinct cousin of modern man.


16a. The first true men: cave painters of the Upper Palaeolithic.


16b. Men of Central Europe twenty thousand years ago.

nearly three-quarters of its length. It then branched into a luxuriant crown of branches and green foliage, with leaves that in some species were over four feet long.

By geological standards the Cordaites had a very short period of success. They were unknown before the Carboniferous Period and died out at its close, to be followed shortly afterwards by the giant lycopods. But other great plants of the time were more adaptable and their smaller and humbler relations are living to this day. For instance, the insignificant 'horsetails' or scouring rushes, commonly found in waste and gravelly places in Great Britain, are the cousins of the gigantic thirty-foot Calamites of the Carboniferous Period. Also many of our modern species of ferns and tree ferns are directly descended from the great ferns of the primeval coal forests.

Now what of the animals who peopled these ancient jungles? In the last chapter we described some of the early amphibians who were slowly evolving through Devonian and Carboniferous times. These were the most advanced creatures of the age, but the warm climate and the luxuriant vegetation of the swamps also provided ideal conditions for the development of the first insects in the world. Many of these belonged to orders and families long since extinct, and several of them grew to gigantic size. At least three species measured over a foot in length, and the most remarkable of all, the giant dragonfly known as *Meganeura* had a wingspan of about twenty-nine inches.

The smaller invertebrates closely resembled the familiar species of today. Spiders scurried through the damp peat, while centipedes and millipedes lurked under stones and fallen logs. Murderous scorpions attacked other insects and each other, and primitive cockroaches whirred through the silent glades. In Nova Scotia the remains of land snails in hollow tree stumps tell how unexpected floods drowned them in their homes and buried them beneath water-borne sediments.

In general, however, the life of the coal forests must have seemed reasonably pleasant and secure. For century upon

CHAPTER 15

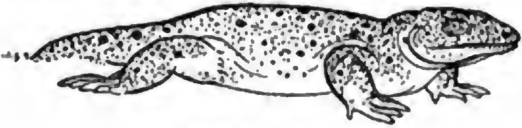
THE MIDDLE KINGDOM

THE Permian crisis of 200 million years ago marks the end of the Palaeozoic Era and the beginning of the Mesozoic, or 'Era of Middle Life'. This rather unsatisfactory name dates from the time of the early geologists, who regarded the Mesozoic as occupying a central position in Earth chronology. It is now known, however, that by the time it had dawned well over half the history of life had already been completed. There is therefore no longer any chronological significance in the name Mesozoic; it must be regarded simply as a kind of reptilian 'Middle Kingdom' between the great eras of the fishes and the mammals.

Today the surviving reptiles are represented by only three main groups: the snakes and lizards, the tortoises and turtles, and the crocodiles. Compared to the mammals, and even to the birds, they occupy a very lowly place in the scale of intelligence and evolutionary success. But this relative insignificance of modern reptiles must not blind us to the fact that during the whole of the Mesozoic Era they were the dominant creatures on the Earth. For no less than 150 millions years they reigned supreme on land, at sea, and in the air. No other race of creatures has ever held the stage of the Earth for so long, nor brought forth such an amazing array of gigantic and spectacular forms. No other race has enjoyed such a dramatic rise to fame, nor suffered such a complete and catastrophic fall.

The birth of this great Middle Kingdom, and the episode of explosive evolution which set it on the road to success, occurred at the height of the Permian crisis. But even earlier, about half way through the Upper Carboniferous Period, there were signs that a new kind of creature was developing from the ranks of the amphibians. This creature had at last discovered the secret of living a complete life on land. It had developed a new kind of egg, with a hard shell and a plentiful supply of food, or yolk, for the embryo, so that it no longer had to return to the water to breed. Also the bone structure of its neck and toes showed that it was evolving a skeleton adapted to new and revolutionary functions; it was, in fact, no longer an amphibian but a reptile.

As we briefly mentioned at the end of the last chapter, the fundamental group of these first true reptiles is known as the cotylosaurs. The name cotylosaur means 'cup-lizard', and is derived from the cup-shaped ring of the vertebra. The actual connecting link between the cotylosaurs and the Carboniferous amphibians is not definitely known, but scientists are now fairly certain that they spring from a primitive stock akin to *Diplovertebron*. When we reach Permian times, however, there are a number of creatures well-fitted for the role of 'missing link'. The classic example is the



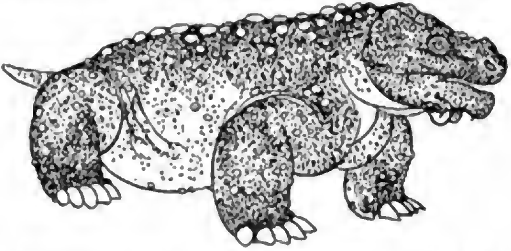
Seymouria, from the Permian of Texas

little *Seymouria*, barely three feet long, from the Permian rocks of Texas. This primitive lizard-like creature combines the attributes of amphibian and reptile in almost equal proportions, and its classification has puzzled palaeontologists ever since its discovery. Some describe it as an amphibian that is almost a reptile, others as a reptile that has just stopped being an amphibian.

With the cotylosaurs proper we have definitely left the amphibians behind and are dealing with the foundation stock of the whole reptile dynasty. They flourished from the time of the coal forests until the dawn of the Mesozoic, reaching their peak in the Permian Period. Remains of cotylosaurs have been found in rock strata in North America, Scotland, and Russia, and a number of especially interesting species occur in the famous Permo-Triassic formations of

South Africa. Here, on the Karroo, there is a vast natural reptilian cemetery occupying an area of 200,000 square miles. Over 1,200 different kinds of fossil reptiles have already been discovered there, and it is estimated that the total number of skeletons entombed in these deposits may approach the altogether fantastic figure of 800,000 million.

The star turn of the Karroo formations so far as the cotylosaurs are concerned is the grotesque creature known as *Pareiasaurus*. Reptiles as a class can hardly be regarded as the most alluring members of the Animal Kingdom, and already



Pareiasaurus, a cotylosaur from the Karroo formations of South Africa

in these early times *Pareiasaurus* was setting an all-time standard in hideousness. Its compact body, which measured between eight and ten feet long, was very broad in proportion to its depth, as if permanently compressed by an invisible burden. Its skin hung in folds round its neck and limb joints, and was covered all over with prominent warty lumps. Its tail was short, stumpy, and ungraceful, and the triangular skull, which was flattened like the body, was encased at the top and sides in solid bone. This last feature was the source of the name *Pareiasaurus*, which means 'helmet cheek reptile'.

The legs were a particularly characteristic feature. These were strong and solid, as indeed they had to be to support their massive owner; but instead of being set on underneath the body, where they would be best able to carry its weight, they sprawled out from the sides with a sharply angled joint between the upper and lower sections. This arrangement, which was directly inherited from the amphibians, represented the height of inefficiency for progression on land. The whole energy of the animal must have been devoted not to speedy or even regular movement, but to an anxious anticipation of the tendency to give at the knees.

Despite its size and exceptionally repulsive appearance *Pareiasaurus* was apparently quite harmless. Its teeth show that it was a vegetarian, not a carnivore, and the claws on its feet were probably designed for digging rather than aggression. We can picture it waddling through the jungle like a huge reptilian tank, crushing the vegetation as it went, and pausing from time to time to masticate mouthfuls of greenery or scratch in the soil for roots. Hideous and ungainly as it was, there is yet something pathetic about this strange creature of the past, caught up in an evolutionary process it could not hope to understand. Its incomplete adaptation made it a failure from the start, and even before the Mesozoic Era had dawned the bones of the last pareiasaur were crumbling to dust under the burning heat of the South African sun.

But not all the cotylosaurs were as unlucky as *Pareiasaurus*. Some forms later evolved into the mighty dinosaurs of the Middle Kingdom, while others were the direct ancestors of the highly successful birds and mammals of today. For the purposes of our story three types of reptiles descended from the cotylosaurs are important. The first are the thecodonts, which were ancestral to the famous reptiles of the Mesozoic Era. The second are the pelycosaurs, which were very near to our own ancestral line and included some of the most spectactular of all early reptiles. The third are the therapsids which were a connecting link between the cotylosaurs and the first mammals.

We shall talk about the thecodonts later in this chapter; here we must first say a word about the other two groups which are so closely connected with our own past. The pelycosaurs, which include the famous 'fin-backed' reptiles of the Permian, are virtually the first reptilian uncles of the human race. That is to say, although they were not in the direct line of descent, they share a common ancestor with ourselves. In view of this fact, we may be relieved to learn that they were tolerably attractive animals. Their general shape was that of a long-tailed lizard, and although their legs still sprawled out sideways instead of being placed underneath the body, they were reasonably graceful and streamlined. One of the most typical forms is that known as *Dimetrodon*, from the Permian rocks of Texas. This was about ten or eleven feet long and, in common with several others of the group, it had a membrane of skin supported vertically along the length of its backbone by a row of long spines. This spectacular feature has made *Dimetrodon* one of the most famous of all prehistoric animals and has led to much speculation regarding the purpose of the membrane or fin. One theory, more remarkable for picturesqueness than scientific probability, is that the reptile was partly aquatic and used its fin for tacking about the estuaries in gusty weather. Another even less convincing proposal is that it was simply a confounded nuisance. The latest and most likely suggestion is that its owner, being like all reptiles a cold-blooded creature, used it as a natural radiator for adjusting its body heat by turning it at varying angles to the sun or breeze.

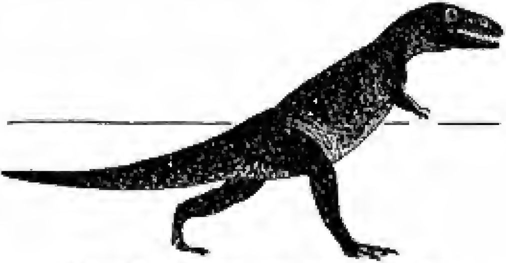
Dimetrodon was an aggressive carnivore with a battery of wicked-looking teeth, but other members of the group were quite harmless. An example of a milder variety is *Edaphosaurus*, which lived entirely on vegetation. It was considerably less svelte than its carnivorous relation, having a thick barrel-shaped trunk for the reception of large masses of masticated plants. Its fin was more regular in height than *Dimetrodon's* and had the added embellishment of bony crossbars sticking out at right angles on either side. In life these crossbars were undoubtedly connected by skin membranes, giving the creature the aspect of a full-rigged ship under full sail.

Compared to the pelycosaurs, the therapsids who gradually succeeded them were an unspectacular group. They are, however, of even greater importance to our story for they were directly ancestral to the mammals, and therefore to ourselves. The fossil remains of therapsids are common in rocks of the Permian Period and the early Mesozoic Era, both in Europe and in the Karroo beds of South Africa, and they are classified into two picturesquely named groups, the Dinocephalia or 'huge heads', and the Theriodontia, or 'beast-toothed' reptiles. One has only to glance at a reconstruction of the twelve-foot monster *Titanophoneus potens*, or the squat and ungainly *Kannemeyeria*, to see how the 'huge heads' got their name. In addition to the massive skull the former had a pair of long dagger-like teeth projecting from its upper jaw; the latter, which was a vegetarian, had an odd beak-like mouth like that of a turtle.

But it is not the 'huge heads' who are mainly of interest to us here, but the 'beast-toothed' therapsids who lived at the same time. These were much closer to the mammals than the 'huge heads' and, as their name implies, they were already developing typical mammalian canines, incisors and molars, each specialized for a different function. This was in strong contrast to the regular peg-like teeth of the more primitive reptiles. They were also evolving limbs that supported their body efficiently from underneath instead of sprawling out at the sides. An advanced example of the group is the efficient and active little carnivore known as *Cynognathus*, or 'the dog-jawed reptile', from South Africa. This creature measured between four and five feet long and combined a reptilian brain with an extremely mammal-like body. Yet despite these advances, *Cynognathus* and his fellow theriodonts must still definitely be classed as reptiles. Their anatomy remained in many respects reptilian, and it is unlikely that they had yet learnt to control their own body heat. This meant that they were unable to survive periods of prolonged cold like the warm-blooded mammals, and remained largely at the mercy of their environment.

So much, then, for the pelycosaurs and therapsids who heralded the Mesozoic Era. We must now return to the thecodonts, or 'socket teeth', a group which, although not closely connected with mammalian ancestry, is of overwhelming importance to the story of the Middle Kingdom. For this is the group ancestral to the giant dinosaurs who were to dominate the Earth for the next 120 million years.

As we mentioned above, the thecodonts stemmed from the primitive cotylosaurs, but they were tackling their evolutionary problems in a totally different way. We have just seen how some of the mammal-like reptiles were achieving greater efficiency on land by evolving legs set well under



Saltoposuchus, a small carnivorous thecodont from the Upper Triassic of Europe

the body instead of sprawling out from the sides. The thecodont answer to the same challenge was largely to ignore the possibilities of four-legged progression, and to concentrate instead on a highly specialized development of the rear limbs. This eventually enabled them to adopt a semi-erect posture, using the back legs for standing and running, and causing the fore-limbs to dwindle to tiny vestigial arms that were not used for locomotion at all.

The carnivorous thecodont *Saltoposuchus*, which lived in Europe 175 million years ago, is a representative example of this new reptilian type. Like most of the group, it was a small, lizard-like creature, less than four feet long, but very active. The hind legs were enormously developed, while the rear part of the body was supported by a long and powerful tail. The fore-legs were as insignificant in comparison as those of a kangaroo, but like all of its kind it always progressed by running, never by hopping. Although so small, it bore a strong resemblance to the great bipedal dinosaurs of the second part of the Mesozoic.

This ancestral relationship to the bipedal dinosaurs is unmistakable, but the thecodonts also gave rise to an infinite variety of other reptilian types. These include our modern crocodiles, as well as the primitive crocodiles known as phytosaurs, and the Mesozoic pterodactyls, or 'winged dragons'. The bipedal stance, therefore, although the most characteristic attribute of the thecodonts, was often modified in other directions. The great variety of the dinosaurs alone is proof of the many different adaptations that were made.

Before going on to describe the dinosaurs, we must conclude this chapter with a brief description of the background of the Mesozoic world. This was more varied, colourful and in many obvious ways more familiar, than the world of the preceding eras. The Permian revolution had brought about sweeping changes in practically every aspect of the Earth's geography, climate, and life. It had initiated an age that brings us to the threshold of comparatively modern times.

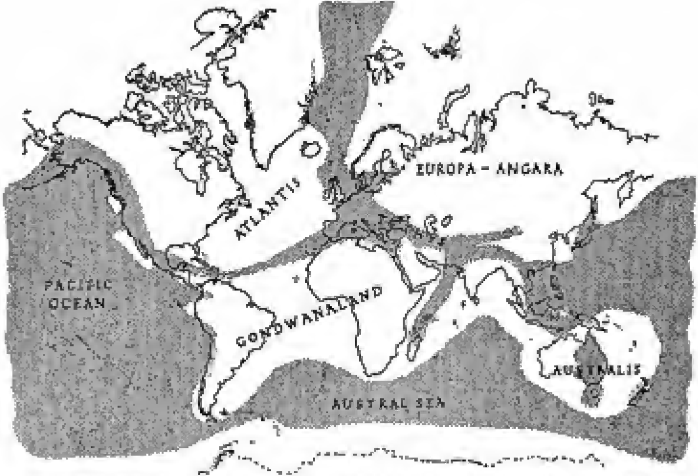
Geologists divide the Mesozoic Era into three main Periods, referred to respectively as the Triassic, Jurassic, and Cretaceous. The first of these, which comes from the Greek word *trias*, meaning 'three', is really a misnomer. It was given to the Period by the German geologist Freidrich von Alberti in 1834 because in Germany the Triassic strata could conveniently be divided into three main layers. Later this was found to be a purely local phenomenon, but the name has nevertheless been retained for Triassic formations all over the world.

The Triassic Period began about 195 million years ago and lasted for 25 million years. It was succeeded by the Jurassic, which was first investigated at the end of the eighteenth century by the famous British geologist William

Smith. Smith, who is popularly known as the 'Father of British Geology', laid the foundations of stratigraphic geology, the science that correlates rock formations by the fossils they contain. He labelled the Jurassic strata the 'Oölite series', but it was later renamed after similar formations in the Jura mountains, and Jurassic is now the name officially adopted.

The last and greatest of the Mesozoic Periods is the Cretaceous, lasting for no less than 70 million years, beginning 140 million years ago. The name comes from the Latin *creta*, meaning 'chalk', and was first applied to the strata now represented by the white cliffs of Dover, and the corresponding formations farther along the coast and across the Channel. Although most of the great chalk deposits of the world were laid down during this Period, chalk is by no means the only, or even the main, constituent of the Cretaceous strata. The name, like that of the Triassic, is therefore misleading, but now has the sanction of long and general usage, and is unlikely to be changed.

From the early Jurassic palaeogeographic map opposite it will be seen how very different were the boundaries of oceans and continents to those shown for the far more ancient Cambrian Period on page 94. The great land masses instead of running as today from north to south, stretched in broad irregular belts from west to east. The northern continents were larger, and the bed of the North Atlantic Ocean was upraised into a huge land mass known as Atlantis. Australia was connected by a land bridge to the disintegrating continent of Gondwanaland, and a vast eastward extention of the Mediterranean into a sea called Tethys cut off India and Malaya from the rest of northern Asia. As is usual with the major cyclic revolutions in Earth history, the Mesozoic began with vast upraised continents which were gradually worn down and covered by the advancing seas. In a more limited context, mountains were also continually being upraised and worn down, while towards the end of the Era an important revolution threw up the great ranges that were later transformed into the Andes and the Rockies.



Geography of the Early Jurassic Period. Shaded areas indicate sea, white areas land

In climate the Mesozoic enjoyed an even longer and more universal summer than did the Age of the Coal Forests. There were exceptions to this, such as an Australian ice cap at the end of the Jurassic, but such conditions were purely local and scarcely interrupted the dramatic and irresistible spread of reptilian life. The mildness of the climate can be deduced from the widespread presence of dinosaurs alone. It is possible for smaller reptiles to survive short periods of cold by retiring to holes and hibernating, but the huge dinosaurs required perpetual warmth as a condition of their existence.

In the plant world there was a great expansion of more modern species, many of them typical of a mild and hospitable climate. In the Petrified Forest of Arizona the trunks of conifers 100 feet long tell of the triumph of the Triassic trees over their giant ancestors of the coal forests. Ferns, tree ferns, and scouring rushes continued to flourish, but there was hardly a survivor of the proud Carboniferous scale trees and Cordaites. Instead, from a sombre background of evergreens, there blazed forth the first brightly hued plants in the world. These were 'flower cones' belonging to the exotic palm-like cycads, characteristic trees of the age of the dinosaurs, whose petrified fronds can still be dug out from the cliffs at the English seaside resort of Scarborough.

In the Jurassic forests, among the pines, there were sequoias, and ginkgos, or maidenhair trees, whose descendants flourish today, almost unchanged after 150 million years. Ferns and cycads covered the open slopes of the hills, and rushes fringed the swamps where the semi-aquatic dinosaurs wallowed in lazy contentment. By the Cretaceous the first deciduous trees had appeared, and there was a rapid spread of the true flowering plants, or angiosperms, which we shall be describing in a later chapter. The landscape was dotted with the familiar shapes of poplars and planes, and the warm spring air was filled with the haunting perfume of magnolias.

The end of the Mesozoic Era thus brings us to the threshold of the modern world. Yet, despite the growing familiarity of flowers and shrubs and trees, the animals of this time were some of the strangest in the whole procession of life. Nearly all of them were reptiles, who had grown from humble beginnings at the dawn of the Mesozoic into the most varied and extraordinary dynasty in the Earth's history. In the next few chapters we shall describe some of the more remarkable of these mighty reptiles who dominated the Earth for so long. We shall speak, too, about the origin of the birds, and the further advances made by the strange reptile-like mammals. Finally, we shall see how the reptilian dynasty reached its climax, and how at its close the first true mammals at long last came into their own.

CHAPTER 16

THE DINOSAURS

No animals of the past have so completely captured the public imagination as the giant dinosaurs of the Mesozoic. Such creatures as *Brontosaurus*, with its massive body and long, snake-like neck, peer regularly from the pages of children's comics and strip cartoons, and next to Martians and space ships are the most essential ingredient in that strange literary phenomenon known as 'science fiction'. Even the commercial world has been unable to resist the lure of the dinosaurs. They are a stand-by for advertising agents on both sides of the Atlantic, and in recent years have equalled the most glamorous film stars as a box office draw at the cinemas.

In view of this immense popularity or, perhaps one should say notoriety, of the dinosaurs, it is odd that they are still the subject of so many misconceptions. Artists and cartoonists who depict them as a serious public nuisance in the Old Stone Age, continually on the prowl for an unsuspecting cave man to carry home to their young, are very far from the truth. Dinosaurs were extinct 70 million years before the first men appeared on the Earth, and were in any case far too unintelligent to be a serious menace to any reasonably active mammal. The idea that they were always enormous and uncontrollably rapacious is also greatly exaggerated. Despite the public determination to have its dinosaurs as large and ferocious as possible, many of them were small and comparatively inoffensive.

This is not to say, of course, that there were no large carnivorous species among the dinosaurs, nor to belittle their well deserved reputation as the most spectacular group of animals in the past history of the Earth. But the great carnivores were restricted to a few species of one particular group, and the vast majority, even of the larger dinosaurs, were as timid and docile as sheep. Quite apart from the large dinosaurs, whether carnivorous or not, there was a far larger assortment of comparatively small and inconspicuous forms, ranging from the size of a barnyard rooster to that of an ordinary domestic horse.

Part of the responsibility for the many misconceptions about the dinosaurs dates back to the nineteenth century, when the group was named by the famous British anatomist Sir Richard Owen. At that time only a few of the larger forms were known, so Owen placed them together in a single natural order with a name based on the two Greek words *deinos*, meaning 'huge', and *sauros*, meaning 'lizard', or 'reptile'. When an increasing number of small forms was discovered the name was seen to be inappropriate, but fortunately the other translation of *deinos*, which is 'terrible', provided a satisfactory alternative. The name dinosaur is therefore now generally regarded as meaning 'terrible reptile' – and no name could more aptly describe the many bizarre forms, large and small, of this incredible group of animals.

Another mistake made by the early investigators was to place the dinosaurs together into a single natural order. It is now realized that there is not one group of these reptiles, but two, the distinction being based on the bones of that part of the body known to anatomists as the pelvic girdle. It is not necessary to go into technicalities here, but we should remember that the two distinct types of dinosaurs, known respectively as the Saurischia, or 'reptile hips', and the Ornithischia, or 'bird hips', differ as much from each other in their atanomy as do, say, the horses and cows of today. The word dinosaur has therefore survived because of convenience and long-established usage rather than any special scientific significance.

The two orders of reptile-hipped and bird-hipped dinosaurs stemmed from the small and agile bipedal thecodonts that we described in the last chapter. They were thus the cousins of the crocodiles, phytosaurs, and pterosaurs, and only remotely connected with the mammal-like reptiles who were eventually to give rise to man. We must repeat, however, that they had solved in a most efficient way of their own the basic reptilian problem of getting their bodies off the ground. All the well-known early dinosaurs of the Mesozoic walked or ran on their hind legs, and even when some later forms returned to a four-legged gait they had progressed far from the sprawling, lumbering crawl of their distant ancestors.

The distribution of the dinosaurs was apparently world-wide. Their remains have been found in every continent, from the north of Europe to the southern tip of Africa, and from the east of Asia to the great dinosaur beds of the western United States. This last region, which covers an area of 100,000 square miles in Utah, Wyoming, Montana, Colorado, and New Mexico, has been the source of nearly all the important New World dinosaur fossils of the Jurassic Period. The New World dinosaurs of the Cretaceous have mainly come from the rocks of the Belly River formation in Southern Alberta, Canada, while in Europe there have been many important finds from all the Mesozoic Periods in France, Belgium, Germany, and especially in the British Isles. It is odd to think that some of the strange creatures we shall shortly be describing once made their homes where now stand such familiar towns as Hastings, Cambridge, Peterborough, and Weymouth.

The dinosaurs first appeared in force during the earliest of the three subdivisions of the Mesozoic Era, the Triassic. By the middle of this Period they already outnumbered all the other kinds of reptiles put together. Compared to some of their successors, none of these early dinosaurs was particularly large, the maximum length being ten to fifteen feet. The great majority retained the thecodont habit of progressing in a semi-erect posture entirely by the use of the hind legs; in fact they were an obvious derivation from such creatures as *Saltoposuchus*, which we described in the previous chapter.

Towards the end of the Triassic larger forms began to appear, and in the European saurischian known as *Plateosaurus* we see the prototype of the giant carnivores of the later part of the Mesozoic Era. This creature measured some eighteen to twenty feet from nose to tail and walked erect on its hind legs. At the time that it lived there is believed to have been a marked seasonal climate in Europe. This has led the German palaeontologist Baron von Huene to draw a graphic picture of great hordes of plateosaurs migrating with the alternating periods of drought and rain between the fertile deltas of the coast and the wooded uplands of the interior, with their rich vegetation of coniferous trees. He believes that many plateosaur fossils originated in those animals who fell by the wayside in the arid deserts that lay in the path of their march.

With the end of the Triassic the dinosaurs began to enjoy their heyday. The terror of the succeeding Period was the giant American carnivore *Allosaurus*, which was over thirty feet long and was equipped with thick sharp claws and wicked sabre-like teeth. At the other end of the scale was the European dinosaur *Compsognathus*, a graceful and delicately made little creature no larger than a small kangaroo. Also prominent at this time was our old friend *Brontosaurus*, the 'thunder lizard', and his even more gigantic relations, *Brachiosaurus* and *Diplodocus*. These sauropods, as they are called, had reverted once more to a four-legged gait on the rare occasions that they ventured forth from the security of their native swamps; they measured between sixty-five and eighty-five feet long and had an average weight of over forty tons. Nevertheless they were harmless vegetarians, who had taken to life in the water to help them support their tremendous bulk. We can deduce the aquatic habits of the sauropods from the distribution of weight in their bones. In several species the bone in the upper part of the body was consistently light, while the rest was comparatively heavy, suggesting that it served the same purpose as the lead in a diver's boots – that is, to preserve stability in the water. Again, several kinds had their nostrils on the crowns of their heads, so that when danger threatened they could still breathe while keeping their only too conspicuous bodies almost entirely submerged.

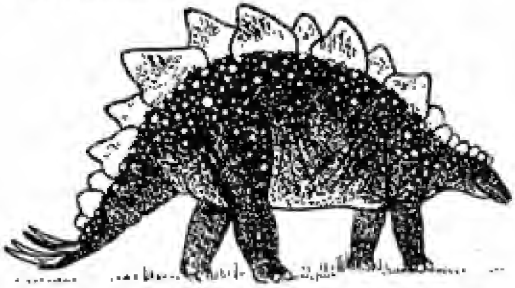
One of the most remarkable features of these huge animals, as of their flesh-eating relatives, was the diminutive size of their brains. The dinosaur brain occupied a tiny recess at the rear of the skull, and its sole function was probably to work the jaws and receive general sensory impressions as to the whereabouts of food and the imminence of danger. The giant sauropods had in addition a swelling of the spinal cord at the base of the vertebral column which acted as a second brain. This was many times larger than the true brain in the head and was responsible for working the muscles of the hind legs and tail. A journalist named Bert L. Taylor on the staff of the *Chicago Tribune* was inspired by this fact to record his reactions in verse:

> Behold the mighty dinosaur,
> Famous in prehistoric lore,
> Not only for his power and strength
> But for his intellectual length.
> You will observe by these remains
> The creature had two sets of brains –
> One in his head (the usual place),
> The other at his spinal base.
> Thus he could reason *a priori*
> As well as *a posteriori*.
> No problem bothered him a bit
> He made both head and tail of it.
> If something slipped his forward mind
> 'Twas rescued by the one behind.
> And if in error he was caught
> He had a saving afterthought.
> Thus he could think without congestion
> Upon both sides of every question.
> Oh, gaze upon this model beast,
> Defunct ten million years at least.

It is probably truer than the author realized that 'no problem bothered him a bit', but this is not due to the duplication of the dinosaur's brain, but because neither brain was sufficiently developed to have any capacity for rational thought. This was a limitation that applied as much to the flesh-eating dinosaurs as to the vegetarians. Thus the typical carnivore of the Mesozoic did not stalk its prey in the deliberate, purposeful manner of the more advanced mammals of today. It probably lived in a state of constant receptivity for unusual sounds or movements, and would then rush in the direction indicated by its senses with a kind of instinctive hunger and blood lust, killing blindly like an automaton without any particular sense of pleasure or excitement or rage. To us there is something especially terrible in these passionless, instinctive murders, so far removed from the more sophisticated thrill of the chase which characterizes mammalian hunting and is still a potent instinct in man himself.

So far in this record of the dinosaurs we have only mentioned members of the Saurischia, or 'reptile hips', but before going on to the last Period of the Mesozoic, the Cretaceous, a word must be said about a typical member of the other great order, the Ornithiscia, or 'bird hips', who exemplifies in the highest degree the limitations of the dinosaurian intelligence. This was the Jurassic dinosaur *Stegosaurus*, a ten-ton, thirty foot long quadruped, found in both America and Europe, with a ridiculosuly small head and a huge body surmounted by two rows of tough but loosely mounted bony plates. *Stegosaurus* had no less than three brains, but despite its size their combined resources were inferior to those of a present-day domestic kitten. The brain in the head was the size of a billiard ball, while the additional 'brains', or enlargements of the spinal cord at shoulder and rump, although larger than the head brain, had the purely functional purpose of controlling the movements of the legs and tail. The failure of *Stegosaurus* to survive beyond the end of the Jurassic was a warning that undue concentration on size instead of brain was no way to avoid the threat of extinction.

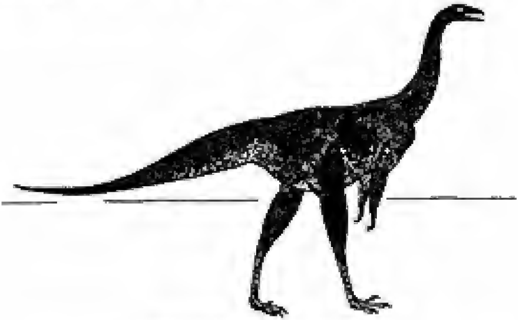
The last 70 million years of the Mesozoic, which constitute the Cretaceous Period, saw a more fantastic array of extravagant forms that even the two previous Periods had been able to provide. Here indeed the dinosaurs enjoyed the Indian summer of their spectacular career. Horned quadrupeds such as *Triceratops* and *Styracosaurus* ranged across the uplands between the steaming swamps, and the Earth was terrorized by the greatest land carnivores of all time. Along the shores of the estuaries strange duck-billed forms such as *Anatosaurus* and *Parasaurolophus* made their appearance, and there was a fantastic new group to whom the burden of its own armour, and the extreme grotesqueness of its bony ornamentation, was already a grim portent of over-specialization and extinction.



Stegosaurus, a ten-ton armoured dinosaur from the Jurassic of Europe and North America

The predators reached their apotheosis in *Tyrannosaurus rex*, the greatest of all earthly carnivores, who strode across the land spreading fear and destruction in its train. This fantastic reptile measured over forty-five feet from nose to tail, with a grotesque skull equipped with a battery of teeth three to six inches long and an inch wide. Its macabre and loathsome aspect was increased by its broad short neck and the tiny vestigial forearms which hung down uselessly from its massive chest.

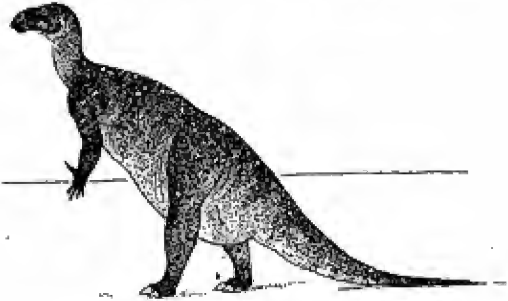
Another fascinating dinosaur of more modest size was *Struthiomimus*, the 'ostrich mimic'. A glance at the reconstruction on page opposite will show at once how it got its name. Its neck and legs were long and slender, and the small skull had toothless jaws, suggesting that it may literally have lived by sucking eggs. Incidentally, the most perfect skeleton of this dinosaur, preserved in the American Museum of Natural History, shows signs of death by the spasmodic convulsions associated with tetanus or strychnine poisoning. We cannot say for certain if this was so, but it suggests a fascinating possibility, and the twisted skeleton helps us more than any words to evoke one aspect of the hazards of this strange world of 80 or more million years ago.



Struthiomimus, the 'ostrich mimic'

One well-known dinosaur from the Cretaceous strata of Europe is of particular interest to us, as it was among the very first of these extraordinary creatures to be scientifically described. In 1822 the wife of Dr Gideon Mantell, the eminent surgeon and palaeontologist, found some peculiar teeth in the lower Cretaceous rocks of Sussex. Mantell was at a loss to identify them and sent them to Baron Cuvier in Paris, who maintained, most inaccurately as it turned out, that they were the teeth of a rhinoceros. Eventually, after discovering further remains, Mantell himself decided that they belonged to an entirely new kind of extinct giant reptile, which he named *Iguanodon*. Much later his decision was dramatically confirmed by the discovery of seventeen nearly perfect *Iguanodon* skeletons in a coal mine in Belgium. *Iguanodon* was a large bipedal type, walking erect with its head about fifteen feet from the ground, like a strangely misshapen lizard. It was a harmless creature, browsing on the vegetation of trees and bushes, and at some of the excavations there could be clearly seen the imprint of its tail where it sat down at intervals on the ground to rest.

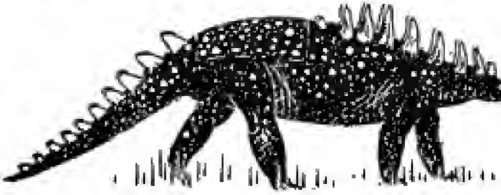
An interesting fact that has been learned from a study of



The giant bipedal dinosaur *Iguanodon*

the Cretaceous dinosaurs is that at least some of them reproduced by laying eggs. Examples of reproduction both by eggs and by the direct birth of living young can be found in different types of modern reptiles, but the behaviour of dinosaurs in this respect was for many years unknown. Then an expedition to Mongolia, sent out by the American Museum of Natural History with the purpose of locating new remains of fossil man, discovered instead a number of well-preserved nests and eggs of the small horned dinosaur *Protoceratops*, together with one example of an unhatched embryo. This important, if unexpected, discovery did not of course prove that every type of dinosaur laid eggs, but it did at least remove our knowledge of one species from the realms of speculation.

As the Cretaceous wore on, grim portents began to appear of the dinosaurs' extinction. These were expressed in the development of several fantastic and over-specialized forms whose growth bore no relation to any effective evolutionary purpose. One example was the grotesque armadillo-like animal *Polacanthus foxi*, from the Isle of Wight; another the even more heavily armoured American dinosaur *Scolosaurus*, a squat, flat, and hideously repulsive creature that looked like a fantastically ornamented tank. The dangerous tendencies exemplified by these creatures reach their climax



Polacanthus foxi, an armoured dinosaur about fifteen feet long, that lived in the Isle of Wight 130 million years ago

in another small American dinosaur called *Troödon*. *Troödon* was literally 'bone-headed', the skull consisting of a thick wall of solid bone covered with an exuberant growth of spikes and ossicles of near-pathological origin. Despite its hideousness we cannot withhold our compassion from this grotesque and pathetic little dinosaur, destined by nature for a brief struggle on Earth, followed by an inevitable and meaningless extinction.

With these last bizarre experiments of natural selection the dynasty of the dinosaurs came to an end. This fantastic group had ruled the land with unbroken success for over 120 million years – the longest period of domination to be enjoyed by a single type of creature in the whole of the Earth's history. In a later chapter we shall describe the manner of the dinosaurs' extinction and the causes that may have been responsible for bringing it about. But first we must retrace our steps for a moment to talk about the reptilian monsters of the Mesozoic seas, and the first attempt by vertebrate animals to make the conquest of the air.

CHAPTER 17

THE RETURN TO THE SEA

It was not only on land that the giant reptiles held sway during the long aeons of the Mesozoic Era. From the time that the first outposts of the Great Invasions had been firmly established, and given rise to those ancestral reptiles, the cotylosaurs, several groups were already exploring the possibilities of a return to the sea. Although superficially this might seem like a retreat, such was not really the case. Rather it was a re-invasion of a familiar territory with the advantage of several million years of evolutionary experience. In fact, the great sea reptiles of the Mesozoic achieved the same success in their own chosen element as did their dinosaur relatives on land.

During the first part of the Permian Period, and perhaps even at the end of the Age of the Coal Forests, several kinds of primitive reptiles were already beginning the return to the water. These belonged to a family known as the mesosaurs – active, slimly built little creatures which seldom measured more than two or three feet in length. Their remains are found in the rocks of South America and South Africa but nowhere else in the world, and palaeontologists believe that they were probably fish-eating forms who lived mainly in fresh or brackish water.

With the dawn of the Mesozoic Era itself, an increasing number of reptiles joined in the re-invasion of the sea. There were primitive turtles, as yet unable to withdraw their heads and legs into the safety of their shells, and a group known as the placodonts who had evolved enormous flat teeth to help them crush the shells of molluscs. One group, known as the nothosaurs, made only a partial readaptation to aquatic life, and probably spent part of their time running over the intertidal rocks, or paddling in shallow water.

It is important to realize that to make the change-over from land to water life involved great problems for the reptiles. It was not simply a question of losing the adaptations they had previously acquired when their ancestors left the sea; they had to start all over again. One of the fundamental laws of nature is that evolution never works in reverse. Thus no animal that has ever come on land can equip itself a second time with typical fish-like fins. It must re-adapt its land limbs or tail to perform the same function in a different way. Often, of course, the new structures bear a superficial resemblance to the old, as in the 'fins' of our present-day mammalian porpoises and dolphins, but anatomically they are built on a totally different plan.

So far we have only mentioned the first tentative efforts of reptiles to return to their ancestral waters before they had presented a serious challenge to the fish, but by the end of the Triassic there was no longer any doubt that sea reptiles were in the ascendant. The mesosaurs, placodonts, and nothosaurs had been replaced by mighty ocean monsters, every bit as fantastic and awe-inspiring as the leviathan and the great sea serpent of popular imagination.

The story of how the fossil remains of these rulers of the Mesozoic deep were first discovered is as romantic as anything in palaeontology. They were found not by a learned scientist, nor by a band of enthusiastic research workers on a Museum expedition, but by a young girl born in the last year of the eighteenth century at the English south coast town of Lyme Regis. Her name was Mary Anning, and her father was a jobbing carpenter whose hobby was picking up and selling the remains of ammonites and belemnites which he found on the sea shore. As we said in an earlier chapter, these fossils are very common on this part of the Dorset coast, and have always been much prized by tourists as curios. Mary Anning used to help her father in his work, and at his death in 1810, was allowed by her mother to continue, for her efforts enabled the now impoverished family to make a little extra money. In the following year, when she was still only twelve years old, she made the first of several dramatic finds which were to bring her international fame. Working with her rock hammer a few hundred yards from Lyme churchyard, she exposed the bones of what she thought in her innocence to be an unusual species of crocodile. It was, in fact, the first skeleton ever to be discovered of an ichthyosaur, or 'fish reptile', one of the largest and best known creatures of the Mesozoic seas.

The skeleton was purchased by the local squire for the princely sum of £23 and eventually found its way to the British Museum. Its discovery was hailed by geologists with the greatest interest and enthusiasm, and when the little girl grew up she was encouraged to embark on the career of a professional fossil hunter. She seemed to have an unerring instinct as to where the fossils could be found, and rapidly unearthed several further ichthyosaur skeletons, including one measuring over twenty-four feet long. But perhaps her greatest triumph was the discovery in 1821 of the remains of the extraordinary sea reptile *Plesiosaurus*, an event which threw the scientific world into a fever of excitement. As if this were not enough, she found, in 1828, one of the earliest examples of a pterosaur or, in popular language, a 'pterodactyl', one of a famous group of flying reptiles which we shall be discussing more fully in the next chapter.

Fittingly a picture of Mary Anning now hangs in the Fossil Reptile Gallery of the British Museum, surrounded by the skeletons of the great Mesozoic reptiles that she was the first to discover. The portrait shows a comfortable middle-aged woman of ample proportions with a pink complexion and humorous eyes. She wears a green cape and a poke bonnet, and her black and white dog, the faithful companion of all her expeditions, lies by her side. In her hand she clutches a geological hammer, and a basket for specimens hangs from her right arm. As one studies the picture one cannot help feeling that this matronly figure would be more at home in a farmer's kitchen, or the parlour of an inn, than on the bleak cliff face among the skeletons of primeval monsters. Yet Mary Anning won the respect of every famous geologist of the nineteenth century, not excepting the great Baron Cuvier himself, and her firmly clasped hammer was the means of carving for herself a special niche in scientific history.

Turning from Mary Anning to her famous discoveries, we find to begin with that the ichthyosaur bears little relation to any of the typical reptiles we have so far described. In fact, if we had come on the skeleton without any special scientific knowledge, we should probably have described it as that of a huge fish. The body, which was from twenty to thirty feet in length, had the torpedo-like streamlining of a typical aquatic animal, while the head was equipped with a long, pointed snout, well suited to cutting through the water. The limbs had completely lost their original reptilian power of progression on land, and had evolved into highly specialized fin-like flippers.

More recently discovered ichthyosaur skeletons from Holzmaden in Germany have preserved the outline of the soft parts, which show many other obvious similarities with the fishes. For instance, there is a fish-like tail and a fleshy dorsal fin which, although unsupported by bone, is efficiently adapted to its underwater function as a stabilizer. The body outline bears an obvious resemblance to our modern porpoises and dolphins, aquatic mammals who fulfil the same function in the present economy of the seas as did the ichthyosaurs 100 million years ago.

Apart from their general fish-like shape, ichthyosaur skeletons are easily identifiable by several other features. For instance, the huge eye sockets are reinforced round the circumference with hard bony plates, while the backbone appears to be broken and bent downwards at the rearward end. For many years palaeontologists believed that this 'broken back' effect was due to disturbance of the skeleton after death, and several early specimens were mounted with the backbone artificially straightened out. It was later realized, however, that this seeming break was a natural deflection of the backbone into the lower lobe of the tail, where it provided support and assisted with the swimming mechanism.

The extreme adaptations made by ichthyosaurs for marine life, and the uselessness of their fin-like limbs for land progression, shows that they must have reproduced in the water. It therefore seems likely that their young were brought forth alive, without going through an intermediate stage in an external egg. This theory is supported by the discovery of several skeletons containing the remains of baby ichthyosaurs. It was once thought that these must be the bones of accidentally eaten young, but as in every case young and adults have been of the same species, it seems much more likely that their association is due to death in childbirth. In some instances it is possible that labour had taken place after the death of the mother, a phenomenon for which there are several mammalian parallels, even among human beings.

The main rivals of the ichthyosaurs for the domination of the seas were the still larger and more fantastic plesiosaurs, whose remains were also first discovered by Mary Anning. The name plesiosaur means 'near reptile', for it was once thought that plesiosaurs were creatures evolving into reptiles from an earlier group of aquatic animals. This is of course incorrect, and plesiosaurs are now known to be true reptiles who branched off early in their history from the ancestral land-dwelling stock to return to a water-dwelling life.

The typical plesiosaur had a thick, barrel-shaped body, a short tail, and an exceptionally long neck. The largest specimens measured between forty and fifty feet long. Unlike the ichthyosaurs, they were unable to progress by fish-like undulations of the body; they rowed themselves along the surface of the sea by means of their four paddle-like limbs, relying less on speed than manœuvrability in the hunting of their prey. The great length of the neck must also have been a valuable aid. In one Cretaceous plesiosaur known as *Elasmosaurus* the neck contained seventy-six vertebrae, and measured no less than twenty-three feet long – considerably more than the whole of the head, body, and tail added together.

Besides the long-necked species there were other kinds with shorter necks but disproportionately long skulls. The best known example of this type of plesiosaur is *Pliosaurus*, whose remains are common in rock formations near Oxford and elsewhere in England. The typical pliosaur skull averaged from four to six feet in length and was equipped with a battery of sharp teeth, indicating extremely aggressive and predacious habits. The pliosaurs reached their peak in the Cretaceous Period, when one Australian species known as *Kronosaurus* developed a skull over three yards long.

Despite the spectacular aspect of the different kinds of ichthyosaurs and plesiosaurs, the last and mightiest of the sea dragons had still to appear. These were the mosasaurs, a tribe of gigantic predators who were to dominate the world's oceans for the last 30 million years of the Mesozoic Era. The name mosasaur means 'Meuse lizard', from the old Roman word for this Dutch river where the first remains of the creature were found. As long ago as the eighteenth century, mosasaur bones were causing considerable excitement in the neighbourhood of Maastricht, and a skull found in 1770 by a certain Dr Hoffman is the subject of an entertaining anecdote. Hoffman had apparently found this skull in a quarry belonging to a local priest named Godin, and had spent much time and money in having it dug out. Unfortunately when it was safely excavated and removed to Hoffman's home, Godin decided that it was his and brought an action for its recovery. As a landowner and ecclesiastic he seems to have won his case with little difficulty; the skull was returned to him, and there for the moment the matter rested. A few years later war broke out. The fame of the skull had by this time spread far and wide, and the general of the advancing French army, being anxious to enhance his prestige, was considering how he might acquire so unusual a prize for the glory of the Republic. Accordingly, when the town was invested, he gave orders to his artillery that on no account was Godin's house to be shelled, for the mosasaur must be preserved intact and taken as a trophy of war to Baron Cuvier in Paris. Unfortunately for these well-laid plans, when the soldiers broke the defences and arrived at Godin's house, neither priest nor mosasaur were anywhere to be found. Obviously Godin had got wind of the plan and decamped with his treasure to a place of safety. This placed the soldiers on their mettle; the honour not only of the general but of the Republic was at stake, and each man determined to be the first to lay his hands on the skull. Just in case honour failed, Citizen Freicine, who had been put in charge of the affair, offered the added inducement of a reward – not money, of course, which would have been a base prize in such a case (and anyway a somewhat unreliable attraction in time of war) – but 600 bottles of the finest Alsatian wine. These tactics worked like magic. Within twelve hours of the announcement of the reward, Freicine was told that the coveted skull had been brought into military H.Q. by a perspiring platoon of soldiers. Thus honour was satisfied, a barrack-room party of unprecedented quality assured, and finally (and we must hope not as too much of an afterthought), Baron Cuvier was able to examine one of the finest and most interesting skulls ever to be offered to the Institute of France.

The first investigation of the mosasaur skull did in fact reveal a creature fully in keeping with the legend built up by its romantic history. This impression was confirmed by new discoveries of bones, and palaeontologists soon had a complete picture of this extraordinary sea dragon. The larger specimens reached a length of forty feet or more and were shaped like gigantic lizards. They must have been able to swim with great speed and power, propelling themselves forward by their massive tails, and using their flippers as steering and balancing organs. Superficially they bore some resemblance to the ichthyosaurs, but in reality belonged to quite a different group. They were true lizards, with scaly skins and loosely jointed jaws, which enabled them to swallow exceptionally large prey. The limbs were simple five-fingered flippers, far less well adapted to aquatic life than the ichthyosaurs' fins or even the plesiosaurs' paddles. Yet despite these primitive characteristics the mosasaurs were undoubtedly highly successful marine predators who were more than a match for any of their formidable competitors in the seas.

Although these creatures, and the others discussed earlier on, represent the most dramatic examples of aquatic life in the Mesozoic Era, we cannot conclude this chapter without mentioning a few of the more familiar types of water reptiles that lived at the same time. During most of the Cretaceous Period there were giant forms of several creatures whose smaller relatives have persisted until today. For example, there were the great marine turtles of North America, especially the extraordinary *Protostega*, or 'first roof', whose fossil remains were discovered in 1870 by the American palaeontologist E. D. Cope. The skeleton of this huge reptile was first seen projecting from the ledge of a low bluff in western Kansas, and, when excavated, was found to have a type of anatomy previously quite unknown to science. Twenty-five years later an even larger marine turtle was discovered. This was the great *Archelon*, which measured over twelve feet long and in life must have weighed at least three tons. It had a large, parrot-like beak and probably inhabited the beds of the shallower seas, where it lived on shell fish. One skeleton of *Archelon* has been found with the right hind flipper bitten off well above the heel – evidence of a narrow escape from some marauding mosasaur.

Apart from the turtles, the most interesting of the more familiar reptiles were the crocodiles. All crocodiles have a somewhat prehistoric look, and even our more modern varieties would have fitted very well into a world where plesiosaurs and mosasaurs ruled the oceans, and dinosaurs wallowed lazily in the swamps and estuaries. In the later part of the Jurassic Period marine crocodiles were quite common in Europe. Of these the best known was *Geosaurus*, an odd-looking creature with a pointed snout and a long narrow body and tail. But the most remarkable Mesozoic crocodiles occurred at the end of the Cretaceous, when they achieved the same gigantic size as the other creatures of the sea and land in these autumn years of the reptile dynasty. The Cretaceous crocodiles were not marine forms, but infested the estuaries and lower reaches of the great rivers where there was a rich supply of the clumsy and slow-witted dinosaurs for them to feed on. A typical example was *Phobosuchus*, the cast of whose skull in the Natural History Department of the British Museum measures six feet three inches long, and just under four feet broad. A living specimen of this giant among crocodiles must have measured roughly fifty feet from nose to tail, which is longer by nearly twenty feet than the largest recorded crocodile of today.

By the end of the Mesozoic Era these huge aquatic carnivores of the estuaries and the voracious mosasaurs of the open seas were enjoying the same domination in their chosen environment as the great dinosaurs on the land. The return to the sea, it seemed, had been an unqualified success, for none of these reptiles could know that their very concentration on size and ferocity was leading inevitably to their own destruction. After a brief chapter on the vertebrate conquest of the air, we shall describe this catastrophic climax to the saga of the Mesozoic reptiles and the various explanations that have been put forward to explain it.

CHAPTER 18

THE CONQUEST OF THE AIR

The problem of flight was solved by invertebrate animals quite early in the history of life. There were flying insects as far back as the Devonian Period, and the Carboniferous coal forests abounded in giant dragon-flies and flying cockroaches. Yet the full conquest of the air by the higher animals was postponed for over 100 million years, and no vertebrate had achieved the power of flight before the Mesozoic Era was well advanced. The most successful early pioneers in the end were once again the reptiles, but they were rivalled and eventually surpassed by their close relations, the first feathered birds.

The Mesozoic flying reptiles belong to that famous group of extinct animals, the pterodactyls or pterosaurs. These made their appearance in the Jurassic Period, about 160 million years ago, and their remains were first discovered in the lithographic stone of Solenhofen, Bavaria, in 1784. The bones discovered at this time belonged to a single skeleton, which was at first thought to be that of an amphibian. However in 1809 Baron Cuvier identified it as belonging to an extinct genus of flying reptiles, and proposed that it should be named *Pterodactylus*, or 'wing-finger'. Two decades later, in 1828, the first British pterosaur was discovered at Lyme Regis by Mary Anning, and the investigation of its skeleton by the British anatomist Sir Richard Owen was one of the earliest important contributions to our knowledge of the race.

The flying reptiles were descended like the dinosaurs from the bipedal thecodonts, but followed a quite different line of development. We have seen how in the dinosaurs the disuse of the forelimbs for progression caused these in many cases to dwindle to tiny vestigial arms. With the pterosaur stock a quite opposite kind of transformation occurred. The forelimbs remained strong and well-developed, and one of the fingers gradually evolved into an immensely elongated 'boom', supporting a bat-like membrane known as a patagium. This primitive wing stretched from the elongated finger to the animal's thigh, permitting a somewhat precarious sort of gliding flight. As the creature began to rely more completely on its wings, the rear limbs became reduced in size until they were quite unsuited for walking on land.

Other specializations for flying occurred at the same time. For instance, the breastbone was greatly strengthened to provide a rigid point of attachment for the muscles used in flight, while the tail developed a fin which helped to stabilize the body in the air. To reduce weight, exceptionally large cavities evolved in the skull, and the bones of the skeleton became hollow and filled with air like those of modern birds. Such modifications caused the body to become progressively lighter in proportion to its size, so that a pterosaur with a three-foot wing span is estimated to have weighed little more than half a pound.

In addition to the discovery of the first British pterosaur remains at Lyme Regis some more exceptionally valuable finds were made in the Bavarian lithographic stone. These beds were apparently formed from the deposition of fine sediments in ancient coral reef lagoons, and they have preserved the outlines of such delicate structures as jelly-fish and bird feathers as well as of pterosaur wings. The stone revealed many new examples of the genus *Pterodactylus* which, under its name of pterodactyl, has become the popular symbol of the whole group. Contrary to general belief, the majority of these pterodactyls were no bigger than sparrows, although some specimens grew to the size of large hawks. They probably fed mainly on insects, and the structure of their feet suggests that they were able to hang upside down like bats. The bones of the skeleton were exceptionally fine and delicate, some measuring no more than a millimetre across.

A larger genus of pterosaurs, with the imposing name of *Rhamphorhynchus*, meaning 'prow beaked', also came from the German lithographic stone. These were characterized by long straight tails terminating in diamond-shaped fins for preventing pitching in flight. The wing span was about thirty inches, and the jaws, like those of most early pterosaurs, were equipped with an array of sharp, forward-pointing teeth.

It is significant that all the remains of pterosaurs so far found have occurred in deposits laid down in estuaries or below the surface of the sea. This suggests that they inhabited the coasts and lived mainly on fish or insects caught on long gliding expeditions over the water. Their wings were incapable of the flapping movements typical of birds, and they must have used considerable ingenuity to take advantage of the wind and rising air currents when far out from land. If a sudden calm fell they would have had great difficulty in maintaining their height, and many were probably drowned. Rough weather was also extremely dangerous to them, for once either of their elongated fingers had been fractured by a sudden gust the wing structure would completely collapse. The flying mechanism of pterosaurs was thus greatly inferior to that of the birds, or even of the bats. Birds can lose several feathers without serious consequences, while the bat's wing is supported by several digits for additional strength.

The pterosaurs so far discussed all belonged to the Jurassic, but the giant of the tribe did not appear until the following Period. This was *Pteranodon*, or 'toothless wing', so named from the fact that among the evolutionary changes that had taken place in these later pterosaurs was the elimination of teeth and the development of a bird-like beak. Other changes included the reduction of the tail to a comparatively insignificant stump, and a great increase in size, corresponding to the development of the Cretaceous dinosaurs on land and the giant mosasaurs in the seas. *Pteranodon* was, in fact, the largest flying animal of all time, with a wing span of between twenty and twenty-seven feet.

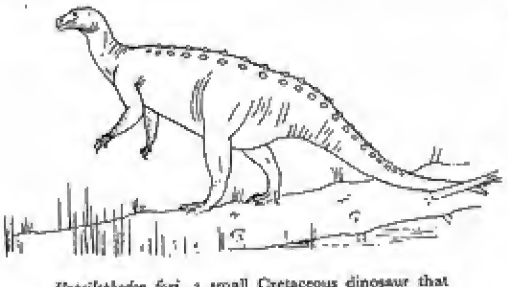
In addition to its gigantic size, *Pteranodon* had several other highly distinctive features. Prominent among these was the great bony projection extending from the back of its head to counterbalance the beak. This was almost as long as the beak itself and added to the creature's already macabre and sinister appearance. Another characteristic feature was the almost complete uselessness of the lower limbs. These were quite inadequate for any form of land progression, and it seems likely that *Pteranodon* spent most of its time soaring over the sea in search of fish, like a modern albatross. When it alighted on the ground to rest, it probably supported itself awkwardly on its elbows, its wings spread out behind it like a partly unfurled umbrella.

The flight of the pterosaurs poses some interesting physiological problems. The prolonged strain of any form of aerial progression presupposes a high rate of metabolism, which is not normally associated with cold-blooded reptiles. This has led some authorities to suggest that all the pterosaurs were to some extent warm-blooded and had a circulatory system that showed great advances over that of their land relations. But even if this was so, it proved inadequate as an instrument of evolutionary survival. The pterosaurs, like the great reptiles of the land and sea, became extinct during the period of revolutionary change that brought the Mesozoic Era to its end.

Another general problem of great interest is what caused the ancestral pterosaurs to attempt flight at all. The wings themselves were obviously an evolutionary advantage to their owner, but the circumstances prompting their growth are still obscure. Two main theories have been proposed. The first is that the connecting link between the thecodonts and the pterosaurs was a tree-dwelling form, probably not unlike the small Cretaceous dinosaur known as *Hypsilophodon foxi*. The wing membrane might have developed in such a creature as a primitive aid in jumping or planing from bough to bough, or parachuting from high trees to the bushes below. The other theory suggests that the membrane developed as an aid to swift running, and gradually grew larger and stronger until the animal found itself able to take off and glide for a few paces along the surface of the ground.

Unfortunately neither theory can be supported by fossil evidence, for no remains of intermediate forms have so far been found.

So much, then, for the pterosaurs – the first and, for many millions of years, the most successful of the vertebrate aviators. But almost from the first the possibilities of flight were being explored by another group of creatures who, although initially slower to develop than the pterosaurs, were to achieve in the long run a far greater success. These were the birds, who were also descended from thecodont ancestors



Hypsilophodon foxi, a small Cretaceous dinosaur that may have been arboreal

but had evolved an entirely different answer to the physical problems involved. Instead of an exaggerated development of a single finger, the birds employed the whole strength of their forelimbs to carry them through the air. Before achieving this stronger and more efficient form of flight they must certainly have reached the condition of warm-bloodedness already mentioned as a possibility in the pterosaurs. At the same time their scaly covering was slowly becoming modified into feathers which, in addition to their value in flying, formed an insulating layer for retaining the internally generated heat of the body.

The skeleton of the first bird was found in 1861 in the same Jurassic stone of Germany that produced such remarkable remains of pterosaurs. The limestone slab containing the skeleton was purchased by the British Museum and, after examination by Sir Richard Owen, the creature was christened *Archaeopteryx lithographica*, or 'ancient wing of the

The Berlin fossil *Archaeornis*, as found in the matrix at Eichstadt

lithographic stone'. Sixteen years later a second fossil bird was found near Eichstadt, and was acquired by the Berlin Natural History Museum. This was at first assigned to the same genus as *Archaeopteryx*, but anatomical differences were later discovered between the two which caused the second specimen to be renamed *Archaeornis*.

The Berlin fossil was by far the better preserved, and its flattened imprint on the stone retained in the abandoned attitude of death an astonishing impression of vitality. Many reptilian characteristics were still apparent. For instance, the jaws possessed true teeth, and there was a long reptilian tail consisting of twenty vertebrae. The skull was more like that of a reptile than a bird, and the wings terminated in three fingers with formidable curved claws. In fact the skeleton might easily have been mistaken for that of a true reptile if the imprint of the creature's feathers had not been preserved on the lithographic stone.

These first birds were roughly the size of crows, but their flight was clumsy and they probably spent more time running up and down the trunks of the cycads, or scrambling in the fronds of the giant ferns, than they did on the wing. Much of their prey, which consisted mainly of insects and small reptiles, was probably taken on the ground, but sometimes they would launch themselves boldly into the air to pursue the giant dragon-flies that flitted across the forest clearings. Of course we know nothing of their colour or the sounds they made, but we can picture in imagination the brilliant hues of their plumage and the chorus of strange cries with which they heralded the Jurassic dawn.

Nothing further is known of avian progress until the Cretaceous Period, when two other interesting types are known from the Kansas chalk of the United States. The first of these, named *Hesperornis regalis*, or 'royal bird of the west', was a water bird similar in habits to our modern divers and loons. It stood about four or five feet high, and seems to have lived entirely on fish. The power of flight had been lost, and the wings had dwindled to tiny vestigial arms, which in life were quite invisible beneath the thick covering of feathers. However, the hind legs were extremely powerful, and spread out sideways at the ankles as an aid to efficient swimming. There were ninety-four sharp teeth in the beak-like jaws, so the bird was well adapted for dealing with its slippery and elusive prey.

The other Cretaceous bird we must mention is the much smaller *Ichthyornis*, which was also a fish eater. This was only nine inches long and somewhat resembled a modern tern. Unlike *Hesperornis* it had well-developed wings and seems to have been capable of sustained and efficient flight. Its jaws were equipped with teeth of reptilian character implanted in individual sockets, but the bones of the wings and feet were remarkably similar to those of modern birds. The brain, like that of all birds, probably had good powers of co-ordination, but was smaller in comparison to body size than that of more recent species.

No other bird remains of any importance are known from the Mesozoic, but even in these primitive types we can see the beginnings of an evolutionary line that has led to the varied and colourful bird population of the world today. Few creatures are more attractive than the birds, and few have enjoyed greater biological success. They are among the most adaptable of living things and have spread to every kind of environment from the tropics to the poles. Some species, like the sparrow, have a world-wide distribution; others, like the penguin and the albatross, are uniquely specialized for a particular environment or way of life. Birds are also infinitely varied in colour, size, and shape. One has only to think, for instance, of the tiny brilliantly hued humming bird, no larger than a humble bee, and the dowdy strutting ostrich, so grotesquely reminiscent of its ancestors in the geological past. Such creatures, at least equally with the mammals, have enriched and gladdened the world and added to our wonder at its multitudinous forms of life. It is one of the most fortunate accidents of Nature that the birds were able to survive the period of crisis and catastrophe in which the Mesozoic reptiles were shortly to be engulfed.

CHAPTER 19

DEATH AND RE-BIRTH

THE end of the Mesozoic Era was a period of wholesale extinction of life. It is the only period in Earth history that can be said to bear some resemblance to one of Baron Cuvier's cataclysms. Of the many kinds of animals inhabiting the Earth at that time, vast numbers were swept completely away. Not only individuals but whole races were destroyed, and extinction overtook the animals of land, sea, and air with equal indifference. When the holocaust was over, the whole aspect of life on Earth had changed. Not a single representative of the dinosaurs, or of the mighty reptiles of the sea and air, remained alive. Of the splendour of the Middle Kingdom all that was left was a few families of crocodiles, some turtles, and the lowly predecessors of our modern snakes and lizards. Even the invertebrates did not escape, for the great races of ammonites and belemnites, which reached their peak in the Jurassic, had vanished from the seas for ever by the end of the Cretaceous. The German geologist Johannes Walther has well named this critical period in Earth history 'the time of the great dying'.

Mammals and birds alone seem to have won through into the last Era of geological time with unqualified success. The mammals especially were destined to reach a far higher standard of achievement than any other group of animals. The last 70 million years of Earth history has been a record of their amazing evolutionary advance. This has culminated in man, who despite his many shortcomings must be regarded as the most highly developed animal to have existed on the Earth so far.

The great Age of Mammals will be considered in more detail in the next chapter. Here meanwhile we must bring up to date the story of early mammalian development. We shall then be able to compare the attributes of the earliest mammals with those of their reptilian contemporaries, and show why they were able to avoid the fate which overtook the rest of Mesozoic life.

Mammals differ from their reptilian forebears in many important ways. Like the birds they are warm blooded, which enables them to sustain long periods of strenuous activity. The great majority of them have eliminated the external egg state in reproduction, the embryo being nourished by complex processes within the mother's body. The young are brought forth alive and, unlike the young of reptiles, are cared for and fed by the mother for some time after birth. Their limbs are better adapted for four-legged progression and they have two definite generations of teeth. In the purely technical field there are marked differences in the anatomy of the jaws and the way the skull articulates with the neck. Most important of all, the mammals have an enormously enlarged cranium which permits a greatly increased development of the brain.

It is this concentration on brain power that above all other developments has given the mammals their distinctive character and brought about their success. The reptiles were larger and more powerful and the birds at least equally active, but neither of these groups had a highly developed intelligence. In fact, as we have already seen, the largest and most ferocious of the dinosaurs were merely grotesque automata impelled by nothing other than their instinctive appetites and hereditary desires. Even the most primitive of the mammals did better than this. For instance, the brain already showed a marked expansion in the region of what are technically known as the 'cerebral hemispheres'. These originally controlled the sense of smell, but gradually evolved into an advanced mechanism allowing for a greatly improved capacity for thought. The growth of these powers eventually allowed the mammals to demonstrate the superiority of intelligence over every other evolutionary asset, and to establish themselves as the rulers of the Earth.

The evolution of the mammals through the 125 million years of the Middle Kingdom is obscure. We have already mentioned the mammal-like theriodonts of the Permian

Period, and said that such creatures as *Cynognathus* were probably closely connected with the basic mammalian stock. But there is no doubt that *Cynognathus*, with all its resemblances to the mammals, had already branched off from the main evolutionary stream. The majority of the known theriodonts were extinct by the end of the Triassic and only a few highly specialized forms lingered on into the beginning of the following Period. The origin of the true mammals must be sought not in such comparatively large and specialized animals as *Cynognathus*, but in their smaller and more inconspicuous contemporaries. Unfortunately remains of such creatures are few and far between. From the whole of the Mesozoic Era not one complete mammalian skeleton has survived, and the only skull dates from the end of the Cretaceous, when the days of the great reptiles were already numbered. Our knowledge of the primitive Mesozoic mammals must therefore be derived from a few fossilized teeth and a handful of fragmentary bones.

On such slender evidence very little can be said about the habits or even the appearance of the first mammals. But what seems certain is that during the whole of the Mesozoic Era they made no great advance in size. There are two lines of reasoning to support this theory. In the first place, we have the evidence of the bones themselves, most of which belong to animals no larger than a modern rat. Secondly, we know that the conditions of the Mesozoic favoured the great rapacity and size of the dinosaurs and that any animal who at this stage had come into direct competition with them would have been doomed to extinction. But although the Mesozoic mammals were small, they were not necessarily as rare as their remains suggest. Small and delicate bones are not easily preserved and frequently escape the attention of the collector.

It seems likely that the twofold necessity of remaining small and of keeping out of the way of the great reptiles may have led the first mammals to explore new environments and ways of life. Thus some forms probably lived in the thick undergrowth of the forests, or actually took to the trees, while others may have spread into the temperate parts of the world or on to high ground where the cold-blooded reptiles could not penetrate. If this were so, the circumstances of their lives probably forced many of them to remain comparatively adaptable and to avoid the more extravagant forms of specialization. At the same time their brains were growing in size and complexity to cope with the problems of survival in a harsh and hostile world. Life was certainly difficult for these first primeval mammals, but the lessons they learned during the long centuries of the Mesozoic schooled them for their future achievements.

In spite of the unsatisfactory nature of the evidence, several distinct orders of Mesozoic mammals can be recognized. Two of these are of particular interest to us: the first, known as the Multituberculata, because, although a side branch of the main mammalian stock, their remains are comparatively well known; the second, known as the Pantotheria, because they may have been directly ancestral to the rest of the great mammalian group.

The multituberculates, or 'many tubercled' animals, were named from the small projections, or tubercles, on their teeth. Members of the group were mostly small, but some grew to the size of a large marmot. They seem to have been vegetarians, for their teeth are highly specialized for gnawing, rather like those of modern rodents. They flourished all through the Jurassic and Cretaceous Periods, and the last members of the group persisted into the new Age of Mammals.

The pantotheres, meaning 'all beasts', or more specifically 'all mammals', are of greater evolutionary significance than the multituberculates. They were common in the Jurassic of Europe and America, and included a wide variety of types. The earliest known genus, from the middle Jurassic of England, was *Amphitherium*, a small insect-eating animal resembling an opossum. A careful study of the teeth of some of the pantotheres has revealed a remarkable likeness to those of later mammals, particularly the marsupials and the monotremes. The marsupials are a primitive group of pouched mammals, which have flourished since the Cretaceous Period and include our modern kangaroos, while the monotremes are the even more remarkable egg-laying mammals, whose modern representatives are the duck-billed platypus and the echidna, or spiny anteater. It seems likely, although the evidence is not conclusive, that the Pantotheria gave rise to the marsupials and were closely related to the ancestral monotremes. They may also have been the foundation stock of all the more advanced mammals of later times.

We now have a reasonably comprehensive picture of the cast that was assembled when the curtain finally came down on the middle act in the drama of life. On land the dinosaurs reigned supreme, and the tiny primitive mammals scurried cautiously through the forest undergrowth or occupied the cooler and more inaccessible parts of the Earth. In the air the pterosaurs, or winged dragons, had reached the limits of their grotesque specializations. At sea the mosasaurs ranged from coast to coast, killing and despoiling without let or hindrance. The Earth, it seemed, was teeming with vital and indestructible forms of life, and the Middle Kingdom, which had already endured for over 100 million years, showed no abatement in its vigour.

But at length with tragic finality the end came. The Earth stirred like some huge giant waking uneasily from sleep, and the renewed mutter of volcanoes gave warning of momentous events. Soon widespread mountain-building split and folded the Mesozoic plains, the seas retreated, and the swampy estuaries were upraised into waterless plateaux. Changes in landscape and temperature laid waste the happy hunting grounds of the dinosaurs, and after the long period of plenty Nature once more ruthlessly applied her law of adaptation or racial death.

As at the transition from the Palaeozoic Era to the Middle Kingdom, geological events were probably the main cause of the great changes in the patterns of life. And they brought in their train many secondary influences which speeded up the process of extinction and made it more complete and absolute than anything the world had hitherto known. For instance, climatic changes caused widespread modifications in plant life, so that the herbivorous dinosaurs were deprived of their food. As their numbers decreased, the carnivorous predators were themselves threatened with starvation. Similar fundamental alterations in the biological economy of sea and air encouraged the decline of the winged dragons and the great reptiles of the oceans.

Yet even when every external factor has been taken into account it is difficult to explain such widespread extinction of all the major forms of life. This has caused scientists to cast around for other theories, the most intriguing of which is the doctrine of racial old age. Old age, it is suggested, is not exclusively the destiny of individuals; it can overtake whole races as well. This occurs when a group of animals, after a period of successful adaptation, finds itself enjoying a favourable environment with plentiful food and a lack of serious competition. Change is no longer a necessary condition of survival, and the hormones, deprived of their true function, begin to indulge in a number of irresponsible experiments. Individuals tend to increase in size or acquire grotesque and useless ornamentation. Soon these developments became a positive handicap to their owners. As size increases, the reproduction cycle occupies a progressively longer time, and fecundity is diminished. Ornamentation often becomes so bizarre that it interferes with the normal functioning of the body machine. The result of such tendencies is to lower the whole vitality of the species and to destroy completely its capacity to adapt. The race, in fact, becomes decadent, and if the slightest strain is placed upon it by a change in its environment it is unable to adjust itself and becomes extinct.

The evidence in favour of this doctrine is inconclusive, and its finer points are still being disputed. But what does seem certain is that extinction can be correlated with over-specialization, and is a result of both internal and external factors. The dinosaurs failed not in spite of their size and rapacity, but because of it. For over 100 million years they had been the victims of a bad biochemical joke, which had given them bulk without brain and physical power without intelligence. Meanwhile deep in the tangled undergrowth of the tropical forests, and in the temperate outposts beyond the boundaries of the reptiles' domains, the mammals were biding their time. The very dangers of their life kept them small, active, and quick-witted, so that when twilight fell on the Mesozoic Era, and the dinosaurs began to falter and fail, they were ready at last to step into their inheritance.

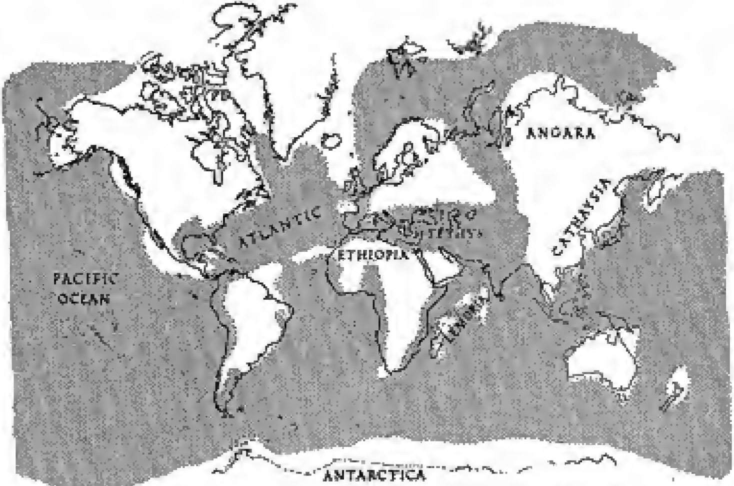
CHAPTER 20

THE AGE OF MAMMALS

THE Cenozoic Era saw the dawn of the Earth as we know it today. It is the shortest of all the geological eras, having lasted only 70 million years, compared to the 125 million years of the Mesozoic and the 325 million of the Palaeozoic. Yet in this, geologically speaking, very brief span of time, all the features of the modern world have taken shape. The seas and continents have acquired their familiar outlines, the great mountain ranges have been sculpted to their present form, and all the modern families of animals have evolved. Towards the end of the Era man himself entered upon the scene, to make the most fundamental of all transformations in the patterns and direction of evolution.

As described in Chapter 6, the Cenozoic Era is broadly divided into seven main sections known as Epochs. The first five of these, known respectively as the Palaeocene, Eocene, Oligocene, Miocene, and Pliocene, constitute a geological Period for which the name 'Tertiary' is in common though not strictly accurate use. This Period lasted from 70 million to approximately 1 million years ago. The last million years of Earth history constitute another geological Period, the Quaternary. The greater part of this, and indeed the whole of it in the opinion of some authorities, consists of a single Epoch, the Pleistocene or Great Ice Age. The time from 8000 B.C. to the present day is variously regarded as part of the Pleistocene, or as a seventh and independent Epoch known as the Holocene.

On the following page is the last palaeogeographic map of the world that it will be necessary to reproduce in this volume. It shows the geography of the Eocene Epoch, when the distribution of land and sea was still very different from what it is today. Especially noteworthy is the great extent of the ancestral Mediterranean, known as Tethys, which covered the whole of the Middle East and southern Asia.



Geography of the Eocene Epoch. Shaded areas indicate sea, white areas land

There was also a broad band of sea which ran from the Arctic to the Indian Oceans, splitting Europe and Asia into two independent land masses, while the two parts of the American continent were not, as now, connected by a land bridge. As the Cenozoic Era advanced, this arrangement of land and sea was greatly changed. Central America began to extend southwards until it was united with South America at what is now the Isthmus of Panama. The sea withdrew from western Russia so that the great Eurasian continent came into being, while Tethys shrank westwards into the present Mediterranean basin. By the Pliocene Epoch the only obvious differences from the map of the world today were the presence of a great expanse of water connecting the eastern Mediterranean with the Black and Caspian Seas, and a peninsula projecting from south east Asia over what is now the Malay Archipelago.

At the same time as these alterations were being made in the world's coastlines a great change was also taking place in the vertical relief of the lands. We have already told how the mountains ancestral to the Andes and the Rockies were upraised at the end of the Mesozoic. These now went through further geological changes and were then gradually weathered to their present shape. In the Old World, the Alpine and Himalayan mountain systems were upraised from the bed of the sea by the compression of the land masses on either side. It is awe-inspiring to contemplate the physical forces that caused these stupendous bodies of matter to be slowly lifted, and then ride over the neighbouring shoreline in huge waves of twisted rock. A few million years after the Cenozoic Era had dawned, these submarine formations had reached a height of over 30,000 feet from their starting point on the ocean floor. We have graphic proof of this today in deposits of Eocene marine fossils upraised to a height of 20,000 feet on the Himalayan chain.

In addition to such episodes of mountain building, the Cenozoic world was shaken by exceptionally violent outbursts of volcanic activity. The Giant's Causeway in Ireland, and the volcanic rocks of Scotland, Greenland, Iceland, and southern India, are the remnants of Cenozoic basalt flows, while the Great Rift Valley of East Africa, and many areas in Central and South America, were devastated by constant eruptions. Later in the Era the volcanic chains of the Mediterranean burst into life, and repeated eruptions in Japan, Alaska, and the East Indies completed the famous 'Girdle of Fire' which now encircles the Pacific.

The climates of this troubled time have shown a not unexpected diversity. As in earlier periods of crustal unrest, ocean currents and prevailing winds were affected by the changing outlines of the continents and the building of new mountain ranges. These in turn affected the temperature and rainfall so that in all the areas of pronounced geological change the local climate varied from Epoch to Epoch. Despite this, the Cenozoic climate showed a marked general trend. In the first part of the Era the world was much warmer than it is today. Magnolias and figs and the descendants of the Mesozoic cycadophytes grew as far north as Alaska. In England in the Eocene the area round London enjoyed a climate similar to that of modern Malaya. Groves of Nipa palms flourished on the Isle of Sheppey, the chines of Bournemouth were covered by a luxuriant jungle of tropical evergreens, and crocodiles basked on the mud-flats of the Thames at Twickenham and Kew.

But as the Tertiary Period wore on, the climate became more extreme. The palms retreated southwards and the vegetation became more temperate in character. Vines, oaks, and ginkgos spread over southern England, and cold winds began to blow from the newly formed polar ice caps. By the beginning of the Pleistocene, as we shall see in the next chapter, a great northern ice sheet extended from the Arctic far south into Europe and over nearly half the continent of North America. This marked the dawn of the Great Ice Age which has finally shaped the landscape and climates of the modern world.

To turn now from geological changes to the new patterns of Cenozoic life, we find that for the first time in Earth history the landscape is covered with familiar vegetation.

Deciduous trees and flowering plants, which appeared in the last period of the Mesozoic Era, were spread over most of the world. Alongside them the older conifers and cycads continued to flourish and many modern species had evolved. Transported back to the Tertiary Period by some kind of Wellsian time machine, we should have found the grass-covered hills, the forests of oak and beech and maple, and the rolling plains that characterize the temperate world of today.

The most remarkable feature of the new vegetation was the triumph of the flowering plants, or 'angiosperms' as they are technically called. The Greek word *angio* means 'box', and the name angiosperm was coined as long ago as 1690 by the German botanist Paul Hermann to signify a plant whose seeds were encased in a seed box or seed vessel. The angiosperms are the highest order of the plant kingdom. They include all the well-known modern deciduous trees, such as birch and walnut and plane, as well as such common flowering shrubs as holly, laurel, and ivy. No race of plants has yet proved itself so versatile. The angiosperms seem equally at home in the sweltering heat of the tropics and the inhospitable lands within a few degrees of the poles. They grow up to the snowline on the highest mountains, and some hundreds of feet below sea-level in inland basins, while different species flourish with equal success in arid deserts or in regions with an annual rainfall of over 500 inches. Their size ranges from a mere twelfth of an inch to the giant redwood trees of America which measure 30 feet across and nearly 350 feet in height; and while some species last only a single summer, others, like the giant baobabs, live for several thousands of years. Yet the secret of this astonishing versatility is still unknown. Even the great Charles Darwin was baffled to account for it, calling the spectacular spread of the angiosperms 'an abominable mystery' which he was quite at a loss to explain.

The radiation of the angiosperms was paralleled by the spread of the new mammalian fauna, whose original and early history we have already described. With the passing of the great reptiles, the mammals assumed their inheritance with the vitality of a powerful race suddenly released from bondage. They spread in a mighty upsurge of evolutionary energy from the equator to the poles and, like the reptiles before them, made a successful re-invasion of the sea and the air. Most aptly can the great bulk of the Cenozoic Era be called the Age of Mammals. These new rulers of the Earth achieved in less than 70 million years a degree of mental progress and physical success that made the far longer dynasty of the reptiles seem like an extravagant and pointless episode. Only in the last geological Period have the mammals begun to show signs of a decline. But even if eventually, like their predecessors, they should fail and die out, they have already produced from their ranks *Homo sapiens*, who is indisputably the highest product of the evolutionary process so far.

In the short space at our disposal it would be impossible to give a systematic account of the Cenozoic mammals, or even to tell how they evolved from the insignificant little creatures we described in the previous chapter. Our survey must therefore be in the nature of a lucky dip in which we shall have to limit ourselves to describing a few of the more impressive types and some of those who have been ancestral to the familiar creatures of today. Nor shall we have time to do justice to the birds or the lowly survivors of the reptile dynasty. The Cenozoic birds, such as the fantastic *Phororhacos*, which was as tall as a man and had a skull as large as a horse's, and the even stranger *Diatryma* and *Anthropornis*, are worth a study on their own. The reptiles were for the most part too like their modern descendants to demand much of our attention.

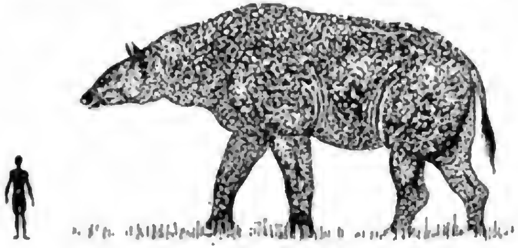
Restricting ourselves to the mammals then, we still have an extraordinarily diverse and interesting array of creatures, some of whom closely rivalled the giant reptiles in size and grotesqueness of ornamentation. During the Eocene, giant hoofed mammals known as titanotheres roamed across the northern continents. Another group known as chalicotheres had feet equipped with massive claws, which they probably used for digging up roots and tubers. The chalicotheres survived in tropical regions of the Old World right down to Pleistocene times, and one of them was responsible for the famous error by Baron Cuvier described in Chapter 5. Most of these animals exceeded a rhinoceros in bulk, and their heads were often ornamented with anything up to six grotesque bony swellings or horns. One huge horned beast named *Arsinoitherium*, from the Oligocene of Africa, had a

Diatryma, an Eocene flightless bird, standing seven feet tall

skeleton twelve feet long and was almost certainly the largest land animal of its day.

Although many of these creatures had a superficial resemblance to rhinoceroses, they did not belong to the true rhinoceros stock. For a true ancestral rhinoceros we have to go to creatures like *Teleoceras*, which lived in North America between 20 and 15 million years ago. One aberrant member of the group known as *Baluchitherium*, from the Oligocene of Asia, was the largest land mammal of all time. It stood eighteen feet high at the shoulder and measured at least twenty-five feet from nose to tail – roughly the size of a double-decker bus.

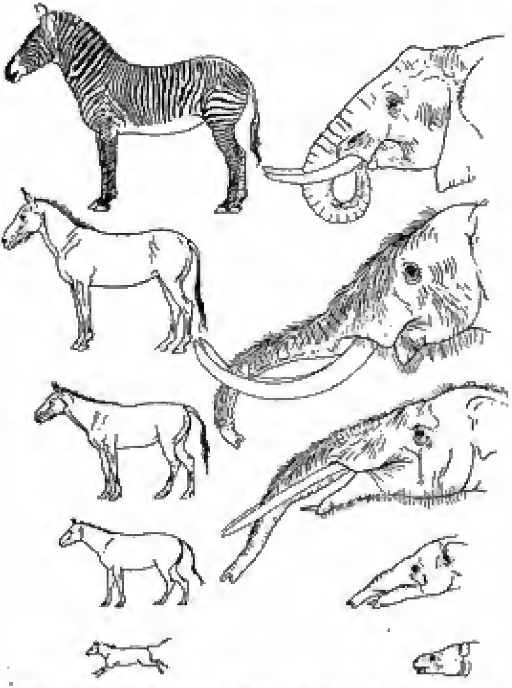
Most of these creatures were probably related to one or other of two groups of primitive hoofed mammals who flourished at the beginning of the Tertiary Period. These were the comparatively lightly built condylarths, and a heavier and more thick-set stock known as the amblypods. The horse tribe originated at the same time and is probably closely related to condylarth stock, if not actually one of its branches. As the horses have had one of the most interesting



Baluchitherium, the largest of all land mammals, compared to a man in scale

and well-documented histories of all types of mammals, we must examine their record in rather greater detail.

The earliest fossil horse is the famous little *Eohippus*, or 'dawn horse', from the Eocene of North America, more correctly known as *Hyracotherium*. It was a graceful creature no larger than a fox terrier, with three toes on the hind feet and four on the front. It was succeeded in the Oligocene by the somewhat larger *Mesohippus*, with three toes on each foot. Next, in the Miocene and Pliocene respectively, came *Merychippus* and *Pliohippus*, the former having three toes on each foot but only using the central one for running, the latter having only one toe visible externally, the outer pair being completely covered by skin. Finally, in the Pleistocene



Ancestry of the Horse and the Elephant. Horse (reading upwards): *Eohippus*, *Mesohippus*, *Merychippus*, *Pliohippus*, and *Equus grevyi* (the modern Grevy's zebra). Elephant (reading upwards): *Moeritherium*, *Palaeomastodon*, *Tetrabelodon*, *Mastodon*, and *Loxodonta africanus* (the modern African elephant).

Epoch, came the modern horse, *Equus*, with its characteristic hoof.

This evolutionary series is particularly interesting in showing how an animal adapts itself increasingly well to its environment and the needs of its life. The ancestral horse doubtless had five toes, like its reptilian and early mammalian forebears. With the need for increased speed, however, it began to run for longer and longer spells on tiptoe, thus carrying most of its weight on the three central toes of each foot, the outer pair being lifted off the ground. Gradually these unused toes became vestigial, until eventually in *Mesohippus* they had completely disappeared. As time went on, the next pair of toes was also affected, so that the animal was running on the central toe of each foot. This is the stage reached in *Merychippus*, where the weight is carried on a strong central toe while the two remaining toes on each foot dangle uselessly on either side and are already beginning to disappear. In *Pliohippus* they are not even externally visible, while in the modern horse, which represents the final stage of this line of development, they survive only as vestigial splint bones and the central toe has hardened into a large tough hoof.

Another exceptionally interesting line of development can be followed in the elephants. Elephant history begins with the little creature known as *Moeritherium* from the Eocene of Egypt. This stood about two feet high at the shoulder and had neither tusks nor trunk, although its upper lip was prehensile like that of a modern tapir. From the beginning of the Oligocene an immense radiation of types occurred. The animals became larger, and their second incisor teeth developed into the gigantic tusks which characterized many extinct species and are still seen in most impressive form in the African elephant of today. But this increase in size, and the growth of tusks, did not prove to be entirely an asset. A stage was reached when the animal's head was too far from the ground and its tusks too prominent for it to reach its food without difficulty. Nature's answer to the problem was the prehensile trunk. This fantastic organ enabled the elephant to reach beyond the points of its tusks to gather vegetation, and to suck up water without bending to the ground.

Despite the survival of two types of elephants to the present day, the race itself must be regarded as a failure. Except for the modern Indian and African species, the infinite variety of forms that evolved from *Moeritherium* have all become extinct. For instance, from the early group known as the mastodons, not a single species survived till the end of the Pleistocene. Yet throughout the Tertiary

Synthetoceras, a deer-like ruminant from the Pliocene of North America

Period this group was represented by a well-diversified array of species. In Oligocene times in Egypt there dwelt a primitive mastodon, called *Palaeomastodon*, with a pair of tusks in both upper and lower jaws. In the Miocene, there was a creature known by the sonorous name of *Tetrabelodon*, with a long lower jaw terminating in short broad tusks. In the Pliocene a more truly elephant-like mastodon appeared, who may have been the ancestor of the famous mammoths of the Great Ice Age. And in addition to all these creatures who were close to the main evolutionary path, there were grotesque side branches, such as *Dinotherium*, whose lower tusks curved backward like the claws of a gigantic cat.

Parallel with the development of the elephants many other mammals were making interesting evolutionary experiments. Some of these repeated the mistakes of the dinosaurs and the early giant mammals by concentrating on great size or grotesque ornamentation. Thus one aberrant genus of the camel family carried its head over nine feet from the ground, while in America there was a giant pig which measured ten and a half feet from head to tail and stood higher than a man at the shoulder. In South America the outstanding members of the Cenozoic cast were a

An early Cenozoic creodont called *Hyaenodon*

ground sloth over twenty feet long and two genera of gigantic armadillos. The Australian *Diprotodon*, the largest known marsupial, closely resembled a modern wombat enlarged to the size of a rhinoceros, while the palm for useless ornamentation must surely go to an extraordinary deerlike ruminant called *Synthetoceras*, which had a fantastic double horn on its nose like a pitch-fork.

Preying on these Cenozoic herbivores were a varied tribe of flesh-eating animals, whose origin and development we must now briefly describe. The flesh-eaters of today are represented by a number of large and successful groups broadly divisible into the familiar cat and dog tribes, but including also such widely dissimilar creatures as the bears, racoons, and civets, and the seals and sea lions of the oceans. Despite their varied forms and ways of life, all these creatures were probably descended from a single primitive group known as the miacids which flourished in the first half of the Tertiary Period. The miacids originated in their turn from a group of tiny insect-eating mammals of the Mesozoic.

None of the miacids so far discovered was much larger than a weasel, a creature which they closely resembled in shape. A typical form was the little *Cynodictis* from the Oligocene, which was probably equipped with retractile claws like a modern cat. Contemporary with the miacids, but larger in size, was the richly varied race of the creodonts, who must have been the scourge of the large herbivorous animals that roamed in vast numbers across the plains. The giant of the tribe, known as *Andrewsarchus*, had a skull three feet long, and was the largest flesh-eating mammal in the history of the Earth.

But the best known of all Cenozoic carnivores, who rose to power with the passing of the creodonts, were the magnificent stabbing cats of the Pliocene and Pleistocene. These are the creatures popularly but inaccurately referred to as the 'sabre-toothed tigers', because of the extraordinary length of their upper canine teeth. Stabbing cats such as *Smilodon* were among the most beautiful and magnificent of Cenozoic animals, and they probably played a prominent role in the extermination of the ground sloths and other vegetarian giants before they themselves became extinct.

The identification of the many different kinds of fossil carnivores is largely decided by their teeth. Flesh-eating animals kill by biting, but meat is easily digestible and does not need to be finely chewed. Thus in the strict carnivores we find highly developed biting or stabbing teeth capable of piercing thick hide and slicing through muscles and tendons, while the molars for grinding and chewing are greatly reduced. As an example, the cat is well equipped for biting but has no adequate chewing mechanism – a fact that can be easily verified by watching the domestic cat dealing with a tough morsel of cooked meat. On the other hand, herbivorous animals have good grinding molars but lack specialization of the canines. In between these extremes are creatures who subsist on both meat and vegetable food. The dog, for instance, which is not exclusively carnivorous, has preserved efficient molars but has well-developed canines as well.

The flesh-eaters bring us to the end of this brief review of the Age of Mammals. It has necessarily been sketchy, for the Cenozoic rocks, being of comparatively recent age, have preserved a detailed and complicated record that cannot be adequately summarized in a few pages. Many important aspects of the story have not even been mentioned; for example, the return of one group of mammals to the sea, which has led to the evolution of the porpoises, the dolphins, and that greatest of all animals, the whale, which not even the largest dinosaur exceeded in size. Nor have we been able to tell how such mammals as the bats, the phalangers, and the flying foxes made a successful invasion of the air. Such fascinating episodes have had to be sacrificed to the demands of conciseness and to the main object of this book, which is to present the record of Earth history in its broadest outline and in an easily comprehensible form.

There is, however, one part of the mammalian story which has not so far been mentioned, but is yet of greater importance than any other. This is the history of a small group of tree-dwelling insectivores who appeared in the record less than 100 million years ago, and gave rise to the lemurs, monkeys, anthropoid apes, and finally, in the last stage of Earth history, to man. This group, known as the Primates, demonstrated in its most obvious form a principle that had already been proved by the more progressive of the mammalian orders. This principle was the vast superiority of brain over physical strength as a means to survival and power.

We have already described how the great reptiles were instinctive automata rather than thinking beings, and how the aberrant groups of mammals who concentrated on size and useless physical development were simply repeating the reptiles' mistakes. But fortunately not every group of mammals was led into this evolutionary blind alley. Even the lowest forms had made some kind of mental progress, while the more advanced carnivorous groups had achieved a very high degree of intelligence indeed. The Primates brought this process to its culminating point. They avoided the pitfalls of excessive physical specialization and concentrated instead on developing the power of their brains. The story of these developments will be told in the final section of this book, when we shall describe the making of man. But first we must finish the physical story of our Earth through the frozen centuries of the Great Ice Age, which formed the setting for this most recent and dramatic episode in the evolution of life.

CHAPTER 21

THE FROZEN WORLD

FOR many thousands of years during the latest, or Quaternary, period of Earth history the world has been clothed in a great shroud of ice and snow. On several occasions glaciers have advanced from the poles to cover nearly a third of the land surface of the globe, while areas now enjoying temperate, or even sub-tropical, climates have been condemned to a harsh and seemingly endless winter. At the height of the most recent period of intense cold, which occurred about 50,000 years ago, the European glaciers ground southwards to the Thames, while the whole of temperate America became a bleak and inhospitable wilderness.

There have been four such periods of intense glaciation during the million-odd years of the Quaternary Period. Their occurrence was first deduced in 1837 by the famous Swiss-American biologist Louis Agassiz, who discovered that the glaciers of the Alps had once spread out widely over the surrounding lowlands. This led him to suggest that in comparatively recent geological time the climate was far more severe than it is today – a view that was later reinforced by his studies in Scotland and the United States. Although the theory was at first greeted with scepticism, its truth is now universally accepted, and the date and duration of the four Glacial Periods can be estimated with some accuracy.

The first glaciation occurred in the early part of the Quaternary between 1 million and 600,000 years ago; the second and third at 450,000 and 200,000 years ago respectively; and the fourth about 80,000 to 20,000 years ago. These Glacial Periods are known collectively as the Great Ice Age, and they correspond to the Pleistocene Epoch of geological time. This was the Period when the final touches were given to the shaping of the modern world.

The term 'Great Ice Age' has more poetic than scientific truth. The four periods of glaciation which it contains

	YEARS AGO	DIVISION
	HOLOCENE EPOCH, begins c. 8000 B.C.	
PLEISTOCENE EPOCH OR GREAT ICE AGE	80,000	Fourth, or Würm, Glacial Period
	180,000	Third, or Last, Interglacial Period
	220,000	Third, or Riss, Glacial Period
	420,000	Second, or Great, Interglacial Period
	460,000	Second, or Mindel, Glacial Period
	560,000	First, or Early, Interglacial Period
	620,000 or more	First, or Günz, Glacial Period

Divisions of the Great Ice Age

occupied only a small fraction of its length, the major portion being taken up by the three comparatively warm and prolonged Interglacial Periods. The relationships of Glacial and Interglacial Periods, with their names and approximate dates, are shown in the chart on the previous page. They are named after the Alpine localities where the different glacial deposits are best displayed, and the dates, although necessarily approximate, are in accordance with the latest scientific estimates.

One interesting fact that emerges from a study of the chart is that the Great Ice Age may not yet be over. The last glaciation occurred so recently that the Holocene may turn out to be not a new geological Epoch, but a fourth Interglacial Period. The ice is now retreating, but time alone will show whether it will finally disappear to leave the poles exposed, as was the case through so much of Earth history, or whether it will once again advance to plunge the world into the rigours of a fifth Glacial Period. If this should occur unprecedented problems will confront mankind. The ice sheets will cover the sites of many of the major cities of the Northern Hemisphere, and the greater part of the British Isles, as well as large tracts of the United States, will become uninhabitable. If we could glance now at some newspaper of the distant future we might read how vast masses of the world's population were migrating southwards before the advancing ice. Or perhaps we should learn how atomic energy had allowed the scientists of that time to keep the glaciers themselves at bay.

But we must return from these intriguing speculations to the sober facts revealed by our knowledge of the past. We now know that in Quaternary time the ice sheets of the Northern Hemisphere radiated from three main centres. In eastern Canada, round Hudson Bay, there was the great Laurentide ice sheet, which spread southward on occasion to the Missouri and Ohio rivers. Nearer home a Scandinavian ice sheet covered the whole of northern Europe, including most of the British Isles, which at that time were joined to the continent. In Asia the principal ice sheet had its centre in eastern Siberia. The area and thickness of these ice sheets reached immense proportions and their enormous weight caused a marked down-warping of the continents on which they rested. For instance, the Laurentide ice sheet alone had an area of over 4,800,000 square miles, which is larger than the present Antarctic Continent. It was at least 8,000 feet thick at the centre, and its weight caused the whole of eastern Canada to sink by several hundreds of feet. In Europe today parts of Scandinavia are still rising at the rate of two inches every five years after their release from the weight of the last ice sheet, which began to melt about 20,000 years ago.

The causes of these recurrent periods of glaciation, like those of all fundamental climatic changes in Earth history, are incompletely known. It seems unlikely that any of the theories discussed earlier in this book could fully account for the complicated fluctuations of temperature found in the Great Ice Age. The most plausible suggestion is that these were due to variations in the amount of heat actually emitted by the sun, perhaps related to sun spot activity. Unfortunately, however, there is no proof that such variations have occurred on anything like a sufficient scale to produce the comparatively rapid changes which we know to have taken place. We must therefore leave this baffling problem for a subject on which we have more satisfactory information – the effect of these recurrent periods of cold on the evolution of life.

The Pleistocene, being so near to us in time, is the best documented Epoch of the Cenozoic. Fossil remains are abundant, and these have been supplemented on occasion by the preservation of whole animals deep frozen in the Arctic snows. The classic example is the Beresovka mammoth mentioned in Chapter 5, whose flesh was still edible after 20,000 years.

One of the most remarkable facts revealed by the fossil evidence is that the Pleistocene saw a marked decline in mammalian life. This tendency had begun in the previous Epoch with the extinction of several genera and species and the restriction of others to a far more limited range. Then, as the glaciers of the Great Ice Age alternately advanced and retreated across the northern continents, an increasing number of mammals began to fall by the wayside. Even the last 50,000 years has seen the passing of numerous species that were dominant during the earlier part of the Quaternary Period.

It is perhaps significant that many of these vanished types were of large size. Almost every major group of mammals was represented in the Pleistocene by at least one giant form that did not survive into modern times. Among the creatures that perished were the huge Australian marsupials, several kinds of gigantic deer, the bizarre armadillos and ground sloths of South America, and all the mammoths and mastodons of the Old and New Worlds. Climatic extremes and epidemics may have accounted for some of these casualties, but the destruction was on so large a scale that once again we cannot ignore the possible influence of racial old age. Whatever the cause, the mammals today are undoubtedly on the wane. The only exception is man, who with the powers conferred upon him by the growth of his consciousness seems to be embarking on an entirely new stage of the evolutionary adventure.

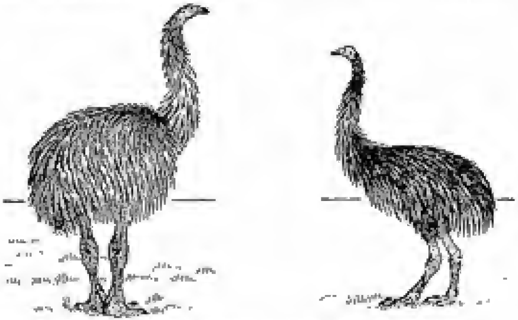
Before succumbing to their fate, several of the Pleistocene giants made initially successful efforts to adapt themselves to their icy environment by growing a protective coat of thick hair. The huge woolly rhinoceros, *Rhinoceros tichorhinus*, was common in Europe down to a few thousand years ago, and is depicted in the cave paintings of the first true men. In England during the Fourth Glacial Period the woolly mammoth *Elephas primigenius* roamed in herds along the valley of the Thames. Southern England was at this time a land of steppe and tundra similar to Lapland and parts of northern Russia today, and the mammoth shared his domain with the reindeer, the arctic fox, and the steppe marmot. Farther south, in France and Spain, the giant cave bear, *Ursus spelaeus*, competed with primitive man for the caves and rock shelters of the Pyrenees.

In the warmer Interglacial Periods a new fauna moved into Europe from the sub-tropical lands lying to the south. Such migrations were made possible by the presence of two land bridges connecting southern Europe with the African continent, and dividing the Mediterranean into a pair of inland lakes. One bridge ran from Spain to Morocco across the present Straits of Gibraltar, the other from the toe of Italy across Sicily to Tunis. As the ice sheets retreated northwards, vast herds of African game moved across these tongues of land, followed by the predacious carnivores of the time. The woolly mammoth was replaced in France and England by a different species, *Elephas antiquus*, which had no need of a protective coat of hair. Hippopotamuses wallowed in the rivers of Oxford, Essex, and Kent, lions hunted in the Yorkshire dales, and scavenging hyenas followed in the train of the marauding sabre-toothed cats.

In North America an equally impressive army of Pleistocene mammals roamed across the prairies or eked out a scanty living on the tundra that bordered the storm-swept ice fields. There were four species of mammoths, ranging from creatures the size of a small Indian elephant to the mighty *Mammuthus imperator*, the imperial mammoth of the southern Great Plains, which stood over fourteen feet high at the shoulder. There were woolly rhinoceroses and camels and at least ten species of wild horses. Finally there was the Royal bison, *Bison latifrons*, with horns over six feet long, and *Bos primigenius*, the aurochs, whose European cousin survived into quite recent times and, like the woolly rhinoceros, was often depicted in the magic drawings of the Stone Age cave painters.

Preying on these herbivores were the great American flesh-eaters such as *Smilodon*, the last of the stabbing cats, and the lion-like *Felis atrox* whose bones are commonly found in the tar pits of Rancho la Brea near Los Angeles. Another creature from these parts was the dire wolf, *Canis dirus*, which probably ran down its quarry in great packs as wolves do today. In addition to such extinct types there was a large assemblage of modern carnivores including the lynx and the puma, or 'American lion', as well as such smaller creatures as weasels, otters, racoons, and badgers.

The record of Pleistocene birds is less lavish than that of the mammals as bird skeletons are not easily preserved, but a number of striking types are nevertheless known. The giant of the time was the ostrich-like moa from New Zealand scientifically known as *Dinornis*. This creature, which sometimes attained a height of over ten feet, was exterminated by



Dinornis, the moa, from New Zealand (left) and *Aepyornis*, from Madagascar

the Maoris quite recently in human history. Another giant form which may have been exterminated by man was *Aepyornis* from Madagascar. Although shorter than the moa, this bird laid the largest eggs known to science, with a capacity of over two gallons. The remains of these giant eggs, discovered by the early navigators, probably inspired Sinbad's stories of the rukh in the Arabian Nights.

The catalogue of extinct creatures which peopled the world during the final stages of the Pleistocene Epoch could be indefinitely prolonged, but with the moa and the half-legendary rukh we must bring it to an end. These strange birds of the southern islands, and the shaggy mammalian giants of the snows, mark the passing of the unfamiliar world of the past and the dawn of the present age. Even as they dwindled to extinction in their citadels the vast legions of modern animals were spread across the globe in much the same form as we know them today. There were lions and elephants in Africa, tigers in India, and huge herds of bison ranging the American plains. The numbers and distribution of these creatures have fluctuated with the passing of the centuries, but the general pattern of modern life was already established 20,000 years ago.

With this final contingent in the procession of life we come to the end of the record of pre-human evolution. Beginning with a void and formless planet, we have watched the growth of life from a microscopic speck of jelly, pulsating at the meeting place of sea and land, to a varied array of organisms of unbelievable size, power, and complexity. We have seen the geological background of the drama sculpted for each different scene and we have reflected on the mighty forces that have brought these changes about. Finally, we have followed the fluctuating fortunes of the successive groups of animals, and wondered at the immense vitality that seemed perpetually to drive them towards their unknown goal.

But the time has now come when we, the human spectators of the drama, must watch the entry of our own ancestors on to the stage. So far the history of the Primates, that great group of mammals from which man derives, has scarcely been touched upon. This is because it is so tremendously important, and so pregnant with possibilities for suggesting the whole future course of evolution, that it was thought best to devote a third section of our book to this subject alone. However foolhardy the search may seem it is in the story of the Primate group, if anywhere at all, that we may find a hint of the meaning of evolution and of the possible goal towards which life is moving.

PART THREE

The Rise of Mankind

CHAPTER 22

MAN'S RELATIONS

UNTIL the last hundred years or so the human race was regarded by most Europeans, whether educated or not, as the final product of a six-day creation. Man, it was assumed, had been selected by God as the climax and *raison d'être* of the creative process, and it was only because of Eve's lamentable indiscretion in the Garden of Eden that he was denied the full enjoyment of his birthright. The animals, although created on the same day as man, were evidently of a different and distinctly inferior stock. The main reason for their existence was doubtless to ensure that the pampered overlords of creation should have a plentiful supply of food.

It was not easy for human beings, who had always regarded themselves as especially privileged beings, to face the fact that they were simply upgraded apes. Darwins' doctrine of natural selection, and particularly his account of the descent of man from animal ancestors, came as a great shock to many naive and simple people who seemed, inexplicably, to think it more ignoble to rise than to fall. But fortunately most of the hysterical opposition to Darwinism has now abated, and what was once the 'theory' of evolution, modified in detail but the same in essence, has passed into the body of scientific knowledge. Today it is no longer necessary as it was even fifty years ago, to defend the simple fact that men, apes, and monkeys belong to the same great family.

The evolution of man during the last million years, when he acquired all his most distinctive attributes, will be considered more fully in the next chapter. Here we must first briefly review the history of the great Primate group to which he belongs and look at some of the existing kinds of animals who can claim to be his nearest relations. Man's closest relatives in the modern world are the four genera of anthropoid apes – gorillas, chimpanzees, orangutans, and gibbons. Second to these come the monkeys, including the advanced types of Africa and Eurasia and the generally more primitive varieties found in South America. Third is the little Indonesian mammal known as *Tarsius*, which is the sole survivor of a group that probably played a very important part in the ancestry of the higher Primates. Finally come the lemurs, an extremely primitive branch of the Primate stock now almost entirely confined to the island of Madagascar.

The resemblances between man and the anthropoid apes are apparent even to the most superficial inspection, and are made doubly clear by a study of Primate anatomy and behaviour. For instance, every bone in man's skeleton can be paralleled by a similar bone in the skeleton of any of the great apes, while his muscles are identical in structure and pattern, his blood circulates by the same mechanism, and even his brain, although much larger in size, is similar in its basic materials and organization. In behaviour we can often see in apes the embryonic expression of many of the patterns found in young or intellectually immature humans. Man is, in fact, far closer to the gorilla and chimpanzee than are the latter to the more primitive members of the Primate group.

Monkeys are considerably further removed from man than the great apes, but many of them still show remarkably human characteristics. For example, their eyes, like those of the apes and man, are set close together in the front of the head, thus enabling them to enjoy stereoscopic vision. The sense of smell is less important than in the lower animals, and the forelimbs are specialized for handling food and other objects. The monkey brain, too, is exceptionally well-developed, and in some of the smaller species has a greater weight relative to that of the body than in any other mammal.

The extraordinary little *Tarsius* from the East Indies, although far less advanced than the monkeys, is also distantly related to the human family. Whereas most mammals have long muzzles, *Tarsius* has the flat face typical of the higher Primates. Its huge eyes are set close together in the head and its brain is large in proportion to its tiny body. Lemurs represent an even more primitive type than *Tarsius*. Many of them have the long fox-like snouts of the less advanced mammalian groups and their eyes are for the most part widely spaced.

Of course, all the modern Primate groups that we have just mentioned are far too specialized for any one kind to be directly ancestral to any other; the idea that 'men are descended from monkeys' is one of the early misconceptions about Darwinism that is still repeated by people who prefer an easy catch-phrase to the trouble of finding out the facts. But what is undeniably true is that at some time in the past a group of animals existed from which men, apes, monkeys, *Tarsius*, and the lemurs all derived. The animals of this group no more resembled modern monkeys than they did the modern *Tarsius*, ape, or lemur, but the potentialities for development in all these directions must have been present or the existing races of Primates would never have evolved.

Have we any grounds for asserting what this ancestral group of animals may have been like? Well, we can say from our knowledge of the way that evolution works that its members were undoubtedly both smaller and less specialized than any of the existing Primate forms. It seems likely, also, that they were arboreal, for every Primate has hands and feet that are in varying degrees specialized for a tree-dwelling life. There are several other lines of evidence connected with eyesight and brain development, but there is unfortunately no space to describe these fully here. We must therefore content ourselves with the summary statement that the remote ancestors of the Primates, and therefore of man, were probably small arboreal insect-eaters very like the modern Oriental creatures known as tree shrews. It is likely that these had evolved from small tree-dwelling reptiles during the Jurassic division of the Mesozoic Era, and that by the time the dinosaurs had met their fate they had already begun to differentiate along the various lines of development that were to give rise to the Primates of today. It is odd to reflect that one of these lines, stemming more than 70 million years ago from a group of small and insignificant mammals, was to evolve into the race that sculpted the Venus de Milo and the Winged Victory of Samothrace, conceived the possibility of wireless communication and atomic fission, and learnt to calculate the distance and internal temperatures of the stars.

A tree shrew (left); *Notharctus*, an Eocene lemur (centre); and a modern tarsier

So far in this discussion of man's relations we have not mentioned the contribution made to our knowledge by the science of palaeontology. Unfortunately the fossil record of the Primates is not nearly so full as it is for other branches of the Animal Kingdom. There are several good reasons to account for this fact. For example, Primates are more intelligent than any other animal group, and therefore seldom sustain death by drowning, which is one of the surest ways in which bones are preserved. They also mainly inhabit forested areas where organic acids in the soil tend to destroy their remains before they become fossilized. Yet despite these factors several fossils of ancestral Primates are known, especially from the early part of the Tertiary Period. The Oligocene is less well documented, but when we come to the Miocene and Pliocene there are some tantalizing remains of early apes, as well as creatures that may have been directly ancestral to man. Finally, in the Pleistocene, the first undoubted human types appear and we see the beginnings of tool-using and tool-making which have caused this time to be called the Old Stone Age. These first stone tools, and the fossils associated with them, will be discussed when we tell what is known about man's immediate ancestry. Here we will restrict ourselves to the remains of earlier and less advanced Primates.

The oldest Primate fossils yet discovered consist of teeth and fragments of bone dating from the Palaeocene and Eocene of Europe and North America. Among the best known are those belonging to the ancestral European lemur *Adapis* and its American relation *Notharctus*, both from the Eocene. There are also numerous fragmentary remains of tarsiers of at least twenty-five different genera from the same Epochs. Some of these may have been ancestral to the monkeys and apes which began to develop in the Oligocene, about 45 million years ago.

Oligocene strata below a dried-up lake in Egypt produced the earliest fossil remains of a true anthropoid. This creature is known as *Parapitheeus*, or 'near ape', and it was reconstructed from a single jaw-bone and a few teeth. It was quite a small animal, scarcely the size of an organ-grinder's monkey, and its teeth suggest that it lived on a mixed diet of fruit, insects, birds' eggs, and small reptiles. Anatomists are agreed that *Parapithecus* was certainly descended from the primitive tarsier stock, and it is very probable also that it was ancestral to the great apes of today, and even possibly to mankind.

Slightly later than *Parapithecus* a somewhat larger Primate lived in the same part of Egypt. This likewise is known only from a single jaw-bone and has been called by palaeontologists *Propliopithecus*. It was about the size of a small gibbon and seems to represent a more advanced stage of evolution than its predecessor. Although the evidence is insufficient to indicate its exact position in Primate ancestry, it too may have been in the direct line of descent that led to the earliest men.

It was probably during the time that these ape-like creatures were chattering in the tree tops of the North African jungles that the higher Primates began to differentiate into the two lines that led, on the one hand, to the modern Old World monkeys and, on the other, to man and the four great man-like apes of today. But palaeontologists are not agreed as to exactly when in Primate evolution the split took place. Some believe that *Parapithecus* was ancestral to both monkeys and apes, others that the monkeys had already branched off from the main stem at an earlier date. But what is now certain is that by the Miocene Epoch there were several great groups of apes living in Africa, who were not only quite separate from the monkey line of development but were the ancestors of the modern anthropoid ape.

The three most important genera of Miocene apes were those known respectively as *Proconsul*, *Pliopithecus*, and *Dryopithecus*. Of these *Proconsul* is known only from Africa, but the other two apparently radiated northwards and eastwards into Europe and Asia during the later part of the Miocene. *Proconsul* – or *Proconsul africanus*, to name the most important species – is known from several jaw-bones and part of a skull discovered in the Lake Victoria region of Kenya Colony and first described by Dr A. T. Hopwood of the British Museum (Natural History). This animal was smaller than a chimpanzee and is regarded by some authorities as a chimpanzee ancestor. On the other hand it still remained sufficiently unspecialized to be a possible forebear of man. The second genus, *Pliopithecus*, was a European form. It is not regarded as part of the human line of descent but was almost certainly ancestral to the modern gibbons. Finally, and most important of all, there is *Dryopithecus*, the 'tree ape', which is widely known from the Miocene of Europe and the Miocene and Pliocene of Asia. Controversy has raged around this animal ever since its discovery, some authorities regarding it as an ancestor of both men and apes, while others believe that the human line branched off on an individual path some time before *Dryopithecus* appeared. The evidence for and against the various theories is based on the specializations of the teeth and bones in the different species of *Dryopithecus* that are known, and unfortunately it must remain inconclusive until further discoveries have been made. Meanwhile all we can say is that *Dryopithecus* resembled a lightly built chimpanzee and was very possibly ancestral to several of our modern apes, even if we ourselves are not numbered among its progeny.

Proconsul africanus, a possible forebear of man

We have now reached a point in our narrative where we can fairly claim to be on the threshold of true human history. The creatures that we shall be describing in the following chapter, although not true men of the genus *Homo*, are undoubtedly either directly ancestral to man or only very slightly off the main line of evolution. But before we embark on this final and in many ways most thrilling episode in Earth history, let us briefly recapitulate the facts of Primate evolution as they have so far appeared to us.

The Primates, we have seen, are the highest order of the

Animal Kingdom. They first appeared with the other mammals when the dinosaurs still dominated the Earth, and to avoid competition with their reptilian overlords they remained comparatively small and restricted themselves to a tree-dwelling life. This enforced seclusion proved unexpectedly to be one of the main causes of the Primates' unique success. Life in the trees demanded strong hands well adapted to holding on to boughs. Jumping from branch to branch called not only for keen eyesight, but for the stereoscopic vision resulting from the migration of the eyes from the sides of the head to the front. Most important of all, the great powers of co-ordination and intelligence required in moving through the tree tops, and avoiding larger and more powerful animals, tended to produce a considerably more efficient and complicated brain.

With many animals specialization is inclined to decrease flexibility and the power to adapt. Fortunately the specializations made by the Primates were not of this kind. Agility, versatile hands, and an enlarged brain were all attributes that could be turned to good account at a later stage in their evolution. Moreover, in several directions the Primates avoided specialization altogether. They became neither strict carnivores nor strict vegetarians and learnt to subsist on anything that came their way. Being mainly tree-dwellers, they retained a flexibility of movement denied to creatures who were permanently confined to the single physical plane of the ground.

But it was undoubtedly the increase in the size of the brain that gave the Primates their greatest evolutionary advantage. They were the first great order of creatures on the Earth to specialize on mental rather than physical power. It is perhaps not too much to say that this diversion of evolutionary energy from physical into mental channels was the greatest single revolution in the history of life since the first appearance of many-celled organisms in the Pre-Cambrian seas. It represented not just another experiment within the limits of the old physical formulae but a completely new line of development. It was virtually a mass mutation, or 'jump', made from one plane of development to an entirely new one.

The first result of the growth of the Primate brain was an enormous speeding up in the rate of evolution. This was aided with the appearance of the first men by the increasing use of external equipment. A fundamental characteristic of man is that he uses his brain to increase the efficiency of his body to cope with any particular situation. Whereas a tiger, for example, kills with teeth and claws which took many thousands of years to evolve, man's brain enables him to manufacture weapons to fulfil the same function in the space of a few hours. Again, whereas many animals adapt themselves to cold by growing longer and thicker coats and are then tied to their chosen environment for life, man can migrate at will between the tropics and the poles, putting on or discarding clothing with every change of temperature. Examples such as these could easily be multiplied and they demonstrate how overwhelming is the advantage conferred by brain power on those animals who are fortunate enough to possess it.

In the next chapter, after dealing with *Australopithecus*, the 'southern ape', which occupies an intermediate position between apes and men, we shall enter on the age of the tool-making Primates, when brain power finally proved its worth and swept man to the domination of the Earth. This time includes the Old Stone Age, which extends from shortly after the dawn of the Pleistocene until about 10,000 years ago, and the Middle and New Stone Ages, which bring us into the age of written history. But tool-making, we may reflect, is not confined to the chipping of stone. It is a stage of evolution that is still in its heyday and seems likely to persist for many thousands of years. Whether it is still the most vital instrument of human progress, or whether, indeed, the growing efficiency of man's material equipment is not now a positive menace to his survival, is a question that must remain in abeyance until the end of our story.

CHAPTER 23

MEN OF THE DAWN

OUR knowledge of the man-apes and sub-men of the dawn of human history is derived from two main sources. First, there is the evidence of fossil remains, of which many new and important discoveries have been made during the last thirty years. Second, there is the evidence of the various implements used by early man in his gradual progress towards culture and civilization. The fossils themselves are comparatively rare and fragmentary, but are nevertheless the all-important clues to the anatomy of the different types of men and their place in the human family. The implements differ from age to age and area to area, and give us invaluable information concerning man's mental progress. They are sometimes found in association with fossil bones, but more often on their own, for their durability has enabled them to survive in conditions which would have caused bones to crumble away.

The family tree of the true men seems to have had its roots in Africa where the great man-like apes also went through the earliest stages of their development. The main centre of interest then shifted to Asia where, as we shall see, the first known forebears of modern man made their appearance. The ancestors of these creatures had probably migrated there from Africa in the Pliocene or early in the Pleistocene, but there is no fossil evidence of intermediate forms to show how they evolved. The final chapters in the story belong mainly to Europe, where there was first a primitive stock that was probably descended directly from African forefathers and then the modern species, *Homo sapiens*, who seems to have migrated westwards during the Fourth Glacial Period from an unidentified locality in Asia. Incidentally, it is a remarkable fact that neither great apes nor men appear to have had any independent evolution in America or Australia. Fossil remains of men and apes are unknown from either of these continents and there are no stone cultures of certain Pleistocene date. America was first peopled with its primitive races by eastward migrations across the Bering Straits in comparatively recent times, while the 'aborigines' voyaged to Australia from south-eastern Asia not more than 15,000 years ago.

	AGE	YEARS AGO	MAIN CULTURES	HUMAN TYPES
HOLOCENE	Age of Metals Neolithic Mesolithic	10,000	Metal cultures, and civilization Advanced stone cultures	*Homo sapiens:* Modern races
PLEISTOCENE	Upper Palaeolithic	75,000	Magdalenian Solutrean Aurignacian	*Homo sapiens:* Cro-Magnon Man, etc.
	Middle Palaeolithic	220,000	Mousterian	Neanderthal Man
	Lower Palaeolithic	600,000+	Levalloisian Abbeville-Acheulean Clactonian Choukoutienian	Pekin Man, Java Man, etc.

The Calendar of Human History (not to chronological scale)

Before we discuss the bones and implements and try to build up a picture of what the earliest men were like, it will help us if we can establish some kind of general framework into which the successive events and discoveries can be fitted. The Calendar of Human History, above, is an attempt to achieve this, but we should remember that there can be no definitive chronology for an age so long ago. At best we can only indicate a few important landmarks and show the general sequence in which the different human and near-human Primates appeared. With the industries we can be even less exact for they persisted for different lengths of time in different areas so that prehistoric culture, like modern civilization, was often more advanced in one place than another.

It will be seen from the Calendar that Pleistocene time is entirely occupied by the single cultural period known as the Palaeolithic, or Old Stone Age. In the succeeding Holocene Epoch we have the cultural periods known as the Mesolithic or Middle Stone Age, the Neolithic or New Stone Age, and finally the Age of Metals, which only now in the twentieth century A.D. seems to be giving place to an age of plastics and atomic science. These three Holocene, or 'wholly recent', periods cover the transition of man from a hunting and food-gathering existence to the highly complex state of society known as civilization, and their detailed discussion lies beyond the scope of this book. Here we must restrict ourselves to the Palaeolithic, which saw the latest stage of man's physical evolution.

The Palaeolithic Age is generally divided into three stages. The Early, or Lower, Palaeolithic began with the dawn of the Pleistocene between a million and 600,000 years ago and lasted until the Third Glacial Period. The Middle Palaeolithic covered the whole of the Third Interglacial Period and the beginning of the Fourth Glacial Period. The Late or Upper Palaeolithic, which saw the appearance of the first true men, lasted from rather less than 60,000 years ago until the end of the Pleistocene in about 8000 B.C. These stages will be reviewed in this and the two following chapters, but first we must tell the story of the extraordinary early Pleistocene man-ape known as *Australopithecus*, who is better qualified than any other Primate for the time-honoured role of 'missing link'.

In 1925 the fossil brain cast and incomplete skull of a young Primate were found in a limestone cave deposit at Taungs in Bechuanaland, South Africa. The remains were examined by Professor Raymond Dart of Johannesburg who was excited to find that they showed a remarkable combination of human and ape-like characteristics. Professor Dart named the creature *Australopithecus*, or the 'southern ape', expressing the view that it was much nearer to man than any previously discovered fossil, and might even be in the direct line of human descent. Controversy raged over this verdict for more than fifteen years until, in 1936 and 1938 respectively, two further finds were made which enabled new light to be thrown on the problem. The first, made by Dr Robert Broom of the Transvaal Museum, Pretoria, was of a fairly complete brain cast with much of the lower half of the skull and face and some of the teeth. The second was made quite by chance by a schoolboy who was taking a short cut over the top of a hill. He saw a skull projecting from a rock and hammered it loose with a stone. This was hardly calculated to improve it, but again by pure chance a fragment of it found its way to Dr Broom, who set off post-haste for the boy's school. At the end of an anxious journey the boy was found and to use Broom's own words, 'drew from the pocket of his trousers four of the most wonderful teeth ever seen in the world's history'.

The finds of 1936 and 1938 were recognized by Dr Broom as belonging to creatures very similar to *Australopithecus*, and he grouped them all together in a single sub-family, the *Australopithecinae*. The similarities of these southern apes to man were now more than ever apparent, and their close connexion with human origins was recognized by many, if not all, authorities. Although the jaws were large, as in chimpanzees and orangutans, the canine teeth were much reduced, as in man, and the skulls had highly arched foreheads and comparatively large brain pans. Most remarkable of all, modifications in the bones connecting the skull with the neck made it clear that the head was placed further back on the shoulders than in apes, suggesting that *Australopithecus* and his cousins almost certainly stood and walked erect. This view has been confirmed by the discovery of a number of skeletal bones, including a hip bone, having a mixture of ape-like and human characters.

On the evidence that has so far come to light anthropologists have hazarded several guesses as to how these southern apes may have lived. They were certainly ground-dwellers, occupying caves in low hillsides far from the great forests, and they probably subsisted by a combination of hunting and food-gathering. The food most readily available to them would have been small mammals such as hares, moles and rock rabbits, and they would doubtless have eked this out with nuts and wild berries. They probably combined together into troops to hunt the smaller gazelles and antelopes of the plains, and although they did not apparently make stone tools, they may have used clubs of wood as instruments of the chase. Even if these South African man-apes were not yet men, they were certainly an unmistakable pointer to the way that evolution was going.

For the second episode in our story the scene shifts from Africa to the Far East. Here, over fifty years ago, were discovered the remains of a creature which is now generally accepted by anthropologists as the most distant known ancestor of living men. This dawn man, who lived during and possibly before the Second Interglacial Period, was discovered in 1890 and 1891 by a young Dutch anatomist named Eugene Dubois. Dubois, while still a student at the University of Amsterdam, had asserted that the East Indies would be a likely place to search for early human fossils. After trying unsuccessfully to persuade the Dutch Government to finance an expedition, he resigned his post in Amsterdam and joined the army as a surgeon in the Dutch East Indies. He spent all his off-duty hours in hunting for fossil bones and at length, after several years of patient searching, his perseverance was rewarded with success. At the village of Trinil, on the Solo River in Java, he unearthed the brain cast of a fossil Primate that was undoubtedly of primitive human type. He named his find *Pithecanthropus erectus*, the 'erect ape-man', and it has since become one of the most famous and important witnesses in the story of fossil man.

Since 1936 several new discoveries have been made in

Java which have greatly added to our knowledge of *Pithecanthropus*. The original remains have been supplemented by a jawbone, several skull fragments, and the skull of an infant, many of them in an excellent state of preservation. There is now no doubt that this ape-man of Java was an erect-walking Primate ancestral to some of the less advanced races of modern men. His brain capacity was about 940 cubic centimetres, which compares with 600 c.c. for the great apes, 1,200 c.c. for primitive modern races, and 1,500 c.c. for a modern European. By our own standards, then, Java man was not very bright, but he represented a great advance over any Primate genus that had previously appeared. His body was short but heavily built, and his skull, with its receding forehead, beetling brows, and protruding mouth, was supported by an exceptionally thick neck. From the evidence of a single fossil femur it is believed by some authorities that his stance and gait was like that of modern man, but he probably carried his head projecting rather far forward from his shoulders. What Java man thought or felt we can only guess at. He almost certainly had some sort of social organization, for even apes have that, and the development of his brain in the special areas associated with speech suggests that he may have had a primitive language for the interchange of ideas. But we have no evidence whatever of his social practices, nor whether he had yet begun to be disturbed by that cosmic fear which lies at the base of primitive religion.

Before leaving the Far East we must mention one other dawn-man who is of even more importance than the ape-man of Java and is closely related to him. This is a creature identified by the Canadian anatomist Professor Davidson Black from a single tooth found in 1927 at the Chinese village of Choukoutien, about forty miles south-west of Pekin. Professor Black named his discovery *Sinanthropus*, or 'China man', but later discoveries in the same area of remains of over forty individuals of this type of man have led to his being placed in the same genus as Java man, with the name *Pithecanthropus pekinensis*, the 'ape man of Pekin'.

Pekin man, if we are to judge by the size of his brain, can reasonably claim to be the first intellectual. Professor Franz Weidenreich, who made an exhaustive examination of all the material available, showed that the brain capacity of the Chinese skulls varied from 850 c.c. to 1,300 c.c., with an average of 1,075 c.c. This average was 215 c.c. higher than that of the Java skulls, and the largest specimen equalled the average brain capacity of the modern South African bushman. These figures are not unimpressive for a race of men who lived between a quarter and half a million years ago.

In other respects also Pekin man was remarkable. Quartz implements found in his caves show that he was a tool maker – possibly the first in human history – while there is evidence of the existence of numerous hearths, which show that he had already discovered the use of fire. In some caves the charred bones of animals associated with the hearths give us a fascinating glimpse of his cooking activities. There is even evidence that fried human brains may have figured on the menu of these earliest Chinese kitchens; several cracked fossil skulls show that their owners undoubtedly met with a violent death, and they have been broken open in a way that would have assisted the extraction of their contents. As no other race of fossil men of this time is known from these regions, the presumption is that Pekin man was a cannibal – and an epicurean cannibal at that.

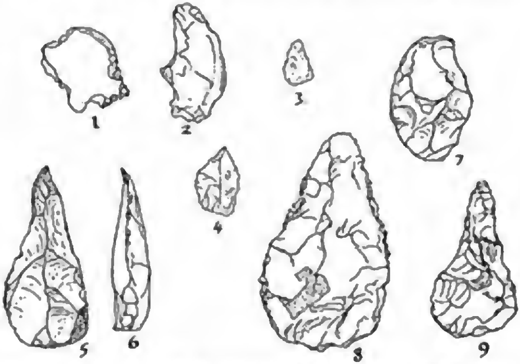
We have now reached the period of human history when the focus of interest begins to shift from Africa and Asia to Europe, where man was destined to enjoy the most advanced stages of his development. The story of European man from the earliest known fossils until the dawn of civilization will form the subject of the rest of this book. But it must be prefaced here by a brief word on the early development of his implements, which will henceforward play an increasingly important part in our story.

The earliest tools to be recognized by archaeologists, which date from early Pleistocene times, have been given the name of eoliths, or 'dawn stones'. These are stones which although bearing evidence of use by man, have not apparently been deliberately fashioned by him. Captive apes today will use a bamboo stick to reach a banana lying just beyond their reach outside their cage. Similarly, primitive men undoubtedly employed sticks and naturally fractured stones to supplement the uses of their hands. The custom of cutting trees with natural unflaked stones, which persists today among the aborigines of Australia, is a remarkable survival from the dawn of Pleistocene time when man was exclusively a tool-using, not a tool-making, animal.

The next stage was the deliberate chipping of stone to produce a sharp implement. The earliest examples of this of which we have detailed knowledge are the quartz tools of the Choukoutien cave deposits of China, already mentioned in connection with Pekin man. It is fascinating to picture a near ancestor of Pekin man casting round for a naturally sharp stone with which, perhaps, to skin an animal he had caught, and then, unable to find one, creating an artificial cutting edge by striking a stone against the rocky wall of his cave. He was, had he but known it, the first experimenter in the long tradition of human craftsmanship that has led to the motor car, the television set and the jet aero-engine.

As time went on knowledge of tool-making spread over the whole of the three continents of the Old World and a number of different cultural traditions sprang up. Some of these had probably stemmed from independent discoveries of the principle of tool-making in different parts of the world; others resulted from the modification of a single tradition as it spread into new areas and was adapted to special uses by different groups of men. Apart from the Choukoutienian culture of Pekin man there were three main traditions of tool-making in Lower Palaeolithic times. These were named respectively the Abbeville-Acheulean, the Clactonian, and the Levalloisian, after the localities where characteristic examples of their tools are commonly found. But the cultures themselves often had an enormous range. Thus hand-axes of Abbeville-Acheulean type are found in such widely separated areas as South Africa, south-eastern India, and southern England while Levalloisian flake tools are found all over Europe as well as in many part of Africa and Asia.

We have no space here for a detailed discussion of the tools in these various cultures, which would in any case be tedious except for the specialist. But it is important to note that their evolution was well under way long before men of our own species appeared on the Earth, and that a Lower



Implements used by early man. 1 and 2: Eoliths. 3 and 4: Choukoutienian. 5 and 6: Levalloisian. 7: Abbevillean. 8 and 9: Acheulean

Palaeolithic hand-axe, primitive as it may appear to us today, represented in its time an extremely high level of cultural achievement. In the following chapters we shall see how these earliest kinds of tools progressed in the direction of greater efficiency and refinement. Meanwhile we should not forget what we owe to our ancestors in the dawn of human life. Seated in their caves and jungle squatting places, laboriously shaping primitive tools from the intractable stone, they were paving the way for all the richly varied crafts and industries of the modern world.

CHAPTER 24

THE FIRST EUROPEANS

MAN has apparently made his home in Europe from early in the Pleistocene, but until the beginning of the Third Interglacial Period – say 180,000 years ago – our knowledge of him depends almost entirely on two enigmatic and fragmentary fossils. These are a heavy jawbone and teeth found in 1907 by Dr Otto Schoetensack in a sand pit at Mauer near Heidelberg in Germany, and the skull and jawbone of the notorious Piltdown man of Sussex, who has caused more controversy and annoyance among anthropologists than any other single specimen in the record of fossil man.

The story of Piltdown man is worth recounting in some detail for it well exemplifies some of the problems of anthropological research, and is not without a surprising *dénouement*. One day in 1908 a Lewes solicitor named Charles Dawson was walking along a farm road near Piltdown Common in Sussex. As well as being a lawyer he was an amateur anthropologist and antiquary, and he was therefore interested to observe that the road was being mended with a type of brown flint not usually found in the district. He enquired about the source of the flints, and learnt that they came from a nearby gravel pit well outside the limit shown on the geological map for the occurrence of this kind of stone. Much interested, he visited the pit and asked the workmen there to keep a good look-out for fossils. A few days later he returned and one of the workmen handed him a fragment of an unusually thick human skull-bone. This was the first link in the chain that led eventually to the reconstruction of Piltdown man.

Encouraged by his success, Dawson returned to the site again and again. He went through the deposit from one end to the other, and exhorted the workmen to continue their searching; but unfortunately no further finds were made. Three years later, however, he was inspecting one of the dump piles when he came across part of the forehead of the skull, including the upper corner of the eye-socket. His perseverance being thus rewarded he decided to submit his finds to the famous palaeontologist Sir Arthur Smith Woodward of the British Museum. Smith Woodward agreed on the immense importance of the find and the two men immediately intensified the search with the aid of specially hired workmen. Next spring more parts of the upper portion of the skull came to light on the dump, and Smith Woodward himself found a piece of the back of the head. Dawson, searching a few feet from the spot where the first find had been made four years previously, recovered half of a lower jawbone. Piltdown man was beginning to take shape, and in 1912, after Smith Woodward had made a reconstruction of the skull, a detailed description of it was given to the scientific world.

Immediately, the Piltdown skull, whose owner had been named *Eoanthropus*, or 'dawn man', became the subject of violent controversy. The age of the find was generally regarded as early Pleistocene, but anthropologists were puzzled by the extraordinary differences between the skull itself and the jawbone associated with it. Whereas the former had the contours and general characteristics of a man of fairly advanced type, the latter was virtually indistinguishable from the jawbone of an ape. This gave rise to the suspicion that, although the skull and the jawbone had been found so close together, they were not correctly associated. The scientific world was divided into two camps. Smith Woodward, Sir Arthur Keith, Sir Grafton Elliot Smith, and other distinguished anthropologists, hotly defended the correctness of the association. It would surely be too great a coincidence, they argued, that the jawbone, without the skull, of an ape, and the skull, without the jawbone, of a man should be found within a few feet of each other. They must, in fact, both belong to a previously unknown type of sub-man with an advanced type of skull and an exceptionally primitive jaw. Other equally eminent authorities disagreed with this view. They felt that the different characteristics of the skull and the jaw made it impossible to believe that they both belonged to the same individual.

Then in 1915 an event occurred which greatly strengthened the claims of the Smith Woodward school of thought. This was the discovery by Dawson, at a place two miles away from the original site, of another *Eoanthropus* skull fragment and a lower molar tooth similar to the teeth found in the first jawbone. It seemed too much to believe that this second find, so exactly consistent with the first in the association of an ape-like tooth with part of a man-like skull, should also be the result of coincidence. Even the most sceptical began to waver and the dawn man of Piltdown, strange mixture though he was of man and ape, was generally admitted to have established his authenticity.

But this was not the end of the story. Several authorities, especially in America, still could not believe in the correctness of associating the skull and the jaw. As it happened these die-hard sceptics were eventually to have the last word, for a third explanation of the Piltdown problem had not yet been considered. It was left to Dr J. S. Weiner of Oxford to propose openly what a number of anthropologists had already suspected in private – that the jawbone of the Piltdown skull was none other than a deliberate and cunningly contrived fake.

In a special bulletin issued by the British Museum in 1953, Dr Weiner, with his two colleagues, Dr Kenneth Oakley and Professor Le Gros Clark, told of tests carried out on the jawbone which had conclusively proved that it belonged to a modern chimpanzee or orangutan. It had been carefully disguised to match the skull, which was likewise proved to be a forgery. The skull fragment and tooth located in the second find were in all probability part of the first specimen and had been deliberately 'planted' two miles away to mislead the investigators. Early in 1955 Dr Weiner brought out a book on the forgery which suggested that Dawson himself must almost certainly have been the perpetrator of this fantastic hoax. Whether or not this is ever finally proved, the deception itself, in the words of the investigators, was 'so extraordinarily skilful . . . as to find no parallel in the history of palaeontological discovery'.

To turn from Piltdown man to that almost equally tantalizing fragment, the Heidelberg jaw, is to step aside for a moment from the possible course of our own ancestry and to consider a race who were very nearly, but not quite, true men. This is the famous race of Neanderthal men who were widely spread over Europe during the Middle Palaeolithic before the climax of the Fourth Glacial Period. The Heidelberg jaw, which dates from the beginning of the Pleistocene, is the earliest evidence we have that men of Neanderthal type were appearing in Europe. In itself it tells us little, but when we reach the deposits of the Third Interglacial Period there is an abundance of fossil remains to help us reconstruct the appearance of the Neanderthal men and the way they lived.

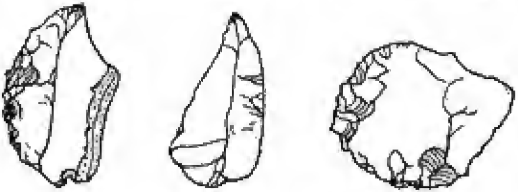
The name Neanderthal man is loosely used to cover nearly a dozen related races, including the ancient Heidelberg man and similar forms who lived in far later times in Europe, Africa and the Far East. For the purposes of our story, however, we shall restrict ourselves to the typical Neanderthaler who lived in Europe for 100,000 years before the first appearance of men of our own species about 50,000 to 60,000 years ago. Neanderthal man, like the race of true men who later supplanted him, was probably of Asiatic origin and a descendant of creatures like the ape-men of Java and Pekin. Although an aberrant side branch of the true human stem he belonged to the same genus as ourselves and has therefore been given the name of *Homo neanderthalensis*. When he became extinct at the beginning of the Fourth Glacial Period he had already acquired several of the social customs, such as burial of the dead and a form of worship, that we normally associate with *Homo sapiens*.

The fossil evidence on which our knowledge of Neanderthal man is based occurs in many parts of Europe, especially the west. The classic find, which gave the race its name, was made in a cave in the Neander Valley near Düsseldorf, Germany, in 1856, and consisted of a skull cap and a few ribs and limb bones. Since then many far more comprehensive finds, including several skeletons, have been made in France, Belgium, Italy, the Channel Islands, and elsewhere. The richest source has been the Dordogne region of France, and especially the caves and rock shelters of Le Moustier, La Ferrassie, La Quina, and La Chapelle-aux-Saints.

What did these human cousins of ours look like, and how did they live? Fortunately their bones and implements help us to give a fairly full answer to these questions. In stature the Neanderthal men were very short and stocky, the males averaging just over five feet in height and the females rather less. Their stance was primitive and their gait slouching, for they lacked the bend of the neck which in man brings the head into an upright position, and their thigh bones were curved forward in compensation. The skull was remarkably large and thick-boned, with a receding forehead and a massive bony ridge over the eyes. Compared to the high, narrow skulls of modern men it was very broad and flat. A big protruding mouth, and the almost total absence of a chin, added to the primitive and brutish aspect of this strange shambling creature who preceded us in the domination of Europe.

Yet despite his unprepossessing appearance we may be surprised to learn that the brain of Neanderthal man was actually larger than ours. The middle-aged Neanderthaler whose remains were found at La Chapelle-aux-Saints had a brain capacity of 1,625 c.c. – considerably more than that of the vast majority of European men alive today. Size, however, is not a reliable guide to quality, and the dimensions of the Neanderthal brain do not necessarily mean that he was brighter than we are. On the other hand, there is no reason whatever to think, as some authorities have suggested that Neanderthal man was incapable of a high standard of co-ordinated thought. In fact we have reason to believe that within the context of his age he had made considerable progress in this direction.

In addition to the evidence of fossil bones the stone industry of the Neanderthalers is a valuable source of information about them. This industry is termed the Mousterian culture, after the French village of Moustier where Neanderthal men once made their homes in the caves. The tools, although still not remarkably advanced, are an improvement on those of earlier types of man. In addition to hand-axes, there are sharp-edged side scrapers for dressing skins, and pointed flints that were obviously used with wooden shafts as spears or darts. There is no evidence that the Neanderthalers had the bow, but balls of limestone found in a cave at La Quina suggest that they may have learnt how to hunt with the bolas. This is a missile consisting of



Implements of the Mousterian culture

two or more small weights joined by a cord, which is thrown at the quarry with the object of entangling its legs and bringing it down. It is still used in Patagonia and elsewhere in South America.

In the early part of the Middle Palaeolithic, when conditions were warm, these strange primitive cousins of ours probably wandered over the great European plains hunting antelope and other small game, and perhaps occasionally bagging a hippopotamus, rhinoceros, or elephant. Their homes were simply squatting places on the banks of streams, with no protection from the elements except a wind-break made of bushes or an animal skin roughly fastened between two trees. Here they lived together in family groups led by the most vigorous male. But although on occasion two or three family groups may have combined together for their mutual advantage, we have no evidence that there was yet as large or complicated a social unit as the tribe. One of the sadder lessons of history is that the idea of co-operative effort seems to be repugnant to human beings, and is only achieved when prolonged discord and misery have finally proved its value.

As the warm conditions began to give place to the rigours of the Fourth Glacial Period, and the woolly mammoth and woolly rhinoceros replaced the vast herds of tropical game on the European plains, life became hard for the Neanderthalers and they took to the caves and rock shelters in the hills. We can picture them huddled round their fires, scraping the skins which by now they had learnt to wear for warmth, or putting a new edge on their weapons for the forthcoming hunt. We can even tell that they performed these tasks with their right hands like ourselves, for the left side of their brain was more developed than the right, and it is the left of the brain that controls the organs on the right of the body. When the Neanderthalers went in pursuit of game they probably lay in wait, like modern tribes, at fords and water holes, attacking the animals as they crossed or drank. They may even have dug traps, although there is no evidence of this, and when game was scarce they were doubtless glad to share the kill of the cave lion if they were fortunate enough to come across his leavings.

The Neanderthal hunters did not eat at the scene of their kill, but brought their food home to their caves. We can tell this because the cave floors are often littered with the bones of animals, some charred with cooking and others broken open for the obvious purpose of extracting the marrow. It is probable, also, that the meat at these orgies was augmented with fruit and wild berries, for the Neanderthalers were certainly no more exclusively carnivorous than their modern successors. We may hope that the strong members of the group provided for those who were aged or sick, but it is only too likely that in difficult times when starvation threatened, these useless members of the family were driven out to die. There was no place for sentimentality or altruism during the freezing centuries of the Ice Age.

Yet that this did not always occur, and that Neanderthal man had some quality of reverence in his savage heart, is shown by the well-authenticated fact that he sometimes buried his dead. One of the best known Neanderthal skeletons is of a young man who has been stretched out with his head resting on his right arm, and both arm and head pillowed on a carefully gathered pile of flints. A hand-axe placed by his side suggests that the Neanderthalers already held the common belief of later times that the dead go to another world and may need the weapons and implements they used on Earth. In addition to the evidence of this and other examples of deliberate burial, it seems likely that Neanderthal men had some instinctive religious beliefs which took shape in formal observances. In one cave, for example, there is a neatly arranged row of skulls of the giant cave bear, suggesting that this place was used as a shrine. Man's capacity for religious emotion, already foreshadowed by these enigmatic symbols in the Neanderthal caves, was soon to be a great power for good, and for evil, in shaping his destiny.

The extinction of the Neanderthal men at the climax of the Fourth Glacial Period seems to have been sudden and complete. The reason for their disappearance was doubtless partly the increasingly severe conditions that accompanied the advancing ice sheets. The number of caves and rock shelters was limited and many Neanderthalers who were unable to secure one doubtless died of exposure. Even those who managed to establish and maintain their right to a home were forced to take part in an increasingly bitter struggle for food. Under the strain of this severe competition it is not surprising that the numbers of Neanderthal men gradually dwindled, and that the survivors found life almost intolerably hard.

But in addition to these natural forces the Neanderthalers were assailed by an enemy from another direction. As the glaciers reached their peak and began to recede, it seems that a new race of men was beginning to infiltrate slowly into Europe from the East. The men of this race, as we shall shortly see, were much more advanced than the Neanderthalers, and they quickly dispossessed them of their caves and established their own culture over the greater part of the European continent. Condemned to a fugitive existence in remote areas with no protection from the bitter cold, the last of the Neanderthalers soon died out, thus bringing to an end a dynasty that had lasted over 100,000 years. The future of the human race lay in the hands of the newcomers, the men from the East, who belonged to the species *Homo sapiens* and were therefore the ancestors of us all.

CHAPTER 25

HOMO SAPIENS TAKES THE STAGE

AFTER the disappearance of the Neanderthal men from Europe at the climax of the Fourth Glacial Period, the principal actors in the drama of Earth history are men of our own kind. Every human race since the dawn of the Upper Palaeolithic is ascribed without distinction of size or colour to this same great species of *Homo sapiens*, or 'wise men'. These men were distinguished from other members of the Primate group, and from their own remoter ancestors, by several important characteristics. For instance, they had a completely erect skeleton and were very much lighter-boned than earlier types of men. Their skulls were narrow and vaulted, with high brows and exceptionally thin walls, while their faces generally lacked such ape-like characters as the heavy brow-ridges and protruding jaws which were typical of their predecessors. Although their brains were no larger than those of the Neanderthalers, they were developed in different areas, giving them greatly improved powers of reason and intelligence. This increased brain power stood *Homo sapiens* in good stead in his battle against the harsh conditions of the Ice Age and his physically stronger Neanderthal rivals.

Despite the suggestion made at the end of the previous chapter, it is not known with complete certainty how the first true men made their entry on to the European stage. Some authorities even believe that they may have been directly descended from their Neanderthal predecessors, but their anatomy makes this extremely unlikely. Another view is that they had been present in Europe from much earlier times, and had developed along parallel lines to the Neanderthalers from a forebear of a quite distinct type. But if this were so, it is odd that no record has survived of the early years of their development, while Neanderthal skeletons are comparatively numerous. By far the most likely theory, therefore, is the one already outlined – that they made their way into Europe from Asia sometime between fifty and sixty thousand years ago, and displaced the Neanderthal races then in occupation.

We are still in the dark concerning the early development of modern man in Asia because of the limited amount of research that has been carried out there. It is, however, reasonable to suppose that he was a direct descendant of some such creature as the ape-man of Pekin. There is nothing in his skeleton that would be inconsistent with this line of descent, and there is every likelihood that further researches in western and central Asia may lead to the discovery of intermediate forms that will bridge the gap.

Before describing the first appearance of true men in the European fossil record, a word must be said about the aspect of the world during the Fourth Glacial Period. The continents had by then assumed their present form, but there were several important, although minor, topographical differences. The Mediterranean, as we have already seen, consisted of a pair of gigantic inland lakes, and Europe was joined to Africa by two land bridges, one running from the toe of Italy across Sicily via Malta to Tunisia, the other at the Straits of Gibraltar. The North Sea was largely dry land, and the Thames joined the Rhine somewhere to the east of the present Straits of Dover. At the climax of the Period, when the Neanderthalers were giving place to true men, the Scandinavian ice sheet extended southwards to Berlin, and glaciers from the Scottish highlands covered nearly the whole of the British Isles. On the frozen wastes bordering the ice fields dwelt the musk ox, the steppe marmot, and the arctic fox, while the seals of the sub-Arctic waters ranged southward to the coasts of Spain. But if any one animal was characteristic of this time it was the reindeer. Great herds of these creatures wandered over the European plain, living on the lichens and mosses of the inhospitable tundra, and themselves forming the principal quarry of *Homo sapiens*. In fact, so vital were reindeer to the economy, and even to the very existence of the first true men, that the closing phase of the Palaeolithic is often referred to as the Reindeer Age.

Although ice, snow, and tundra were typical of much of this time, the grim climate was occasionally punctuated by warmer and gentler spells. During these interludes the reindeer retreated to the north, followed by the woolly mammoth, the woolly rhinoceros, and the saiga antelope, which still survived in Western Europe up to 20,000 years ago, although in diminishing numbers. The tundra was replaced by rolling prairies across which roamed great herds of bison, aurochs, and wild horses. Later, forests sprang up, consisting mainly of birch, aspen, and conifers, and there were increasing numbers of red deer. All these animals formed the prey of the first true men at different times in the closing centuries of the Palaeolithic Age.

Now what of the men themselves? How did their culture differ from that of their Neanderthal predecessors and what were the stages by which they evolved from savagery toward civilization? It should not be thought that the newcomers from the East, although they belonged to the same natural species, were all of identical type. The European men of the Reindeer Age varied as much among themselves as do the European races of today. These differences are apparent not only in their fossil bones, but in their industries, and in the higher manifestations of culture which were gradually added to their purely utilitarian activities.

The most famous, and in many ways the most typical, early representative of *Homo sapiens* in Europe was the physical type known as Cro-Magnon man. The first European example of this type was discovered as long ago as 1823 in the Paviland Cave of the Gower Peninsula, South Wales, associated with the bones of rhinoceros, bear, lion, hyena, and elephant. Its significance was not recognized, however, and it was not until 1868 that the discovery of five complete skeletons at the small rock shelter of Cro-Magnon, at the village of Les Eyzies in France, brought fame to this early ancestor of ours, and provided him with a name.

The Cro-Magnon skeletons were of an old man, two young men, a woman, and a child, all in an excellent state of preservation. They revealed a race of tall, upright men, with relatively long legs and straight thigh bones, only superficially different from the typical Europeans of today. The brain was fully as large as in modern races, that of the old man having a capacity of 1,600 c.c., which is well above that of most twentieth-century adults. This find, which came only twelve years after the discovery of Neanderthal man and less than a decade after Darwin published *The Origin of Species*, caused a great furore and was of immense help to the cause of the evolutionists in the bitter religio-scientific controversy that was then at its height.

A second race of men, rather like the Cro-Magnards but shorter in stature, was the subject of a later and even more spectacular find at Předmost in Moravia. This area seems to have been an Upper Palaeolithic hunting station situated on the highway of great seasonal migrations of big game. Over a hundred different camps have been found since it was first investigated in 1880, and vast accumulations of mammoth bones bear witness to the prowess of the hunters. In the early 1890s Dr K. J. Maška unearthed here a communal tomb containing the bones of no less than twenty individuals, including men, women, and children. The tomb, which appeared to be the Palaeolithic equivalent of the modern family vault, was flanked on one side by a row of mammoth shoulder-blades, and on the other by the lower jaws of mammoths placed in an upright position. The burial had obviously been carried out with great reverence and ceremony, showing that these people were moved to awe and wonder by the mystery of death.

The Cro-Magnon men of France, and the mammoth hunters of Moravia, are regarded by most authorities as the ancestors of modern Europeans, but there is no such unanimity about the status of a third type of man who lived in Upper Palaeolithic times. This type is represented by the famous Grimaldi skeletons, which were found in a cave known as the Grotte des Enfants, near Menton on the Franco-Italian frontier. The cave was so named because in

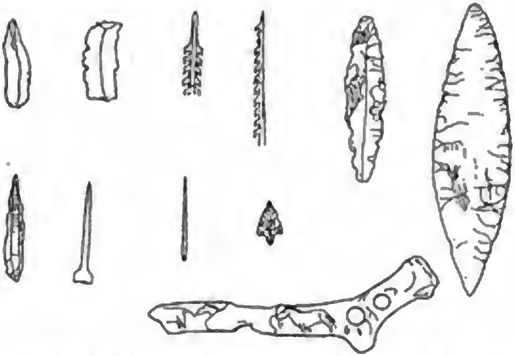
Skeleton of a woman and a youth found in the Grotte des Enfants at Grimaldi

1874 and 1875 two nearly complete children's skeletons were discovered there, but their skulls were so badly smashed as to be of little use for identification. Then in 1900 under the patronage of the Prince of Monaco further researches revealed the skeleton of an old woman and a youth of about sixteen years of age. The skeletons were buried side by side, the woman with her arms doubled under her chin and her knees tightly drawn up to her belly, the boy in a loosely flexed attitude with arms and legs half bent. The boy's skeleton was painted with red ochre, a common ceremonial practice in burials of this time, and there were numerous artifacts dating from the very earliest years of the Upper Palaeolithic. But the most unexpected feature of the burial was that the anatomy of both the skeletons seemed to many authorities to be distinctly negroid in type.

Controversy over the status of Grimaldi man has now been raging for more than fifty years. Those who uphold the negroid theory point to the bulging foreheads of the skulls, and their somewhat projecting jaws, both characters more typical of negro races than European man. They say that the Grimaldi skeletons undoubtedly belong to a negroid stock who migrated into Europe from Africa over one or other of the two land bridges that traversed the Mediterranean at that time. The opponents of this theory base their objections on other technicalities of skull structure. They point out also that no negro remains have been found in North Africa, and it would anyway be extremely unlikely that a negro race enjoying a congenial sub-tropical climate would voluntarily migrate northwards into the frozen world of the Ice Age. The rights and wrongs of these professional wrangles need not concern us here. Enough has been said to show that *Homo sapiens*, although divided into a number of different races, was firmly established in Europe well over 30,000 years ago.

So much, then, for the physical aspect and racial variations of the first true men. But what of their mental development as reflected in their culture and social organization?

Three main stages of Upper Palaeolithic culture are recognized, named after the sites in central and south-western France where characteristic artifacts have been found. The earliest of these is called the Aurignacian, after a cave at Aurignac, forty miles south-west of Toulouse. Second comes the Solutrean, from the village of Solutré, near Mâcon, where there was a famous camping ground of primitive

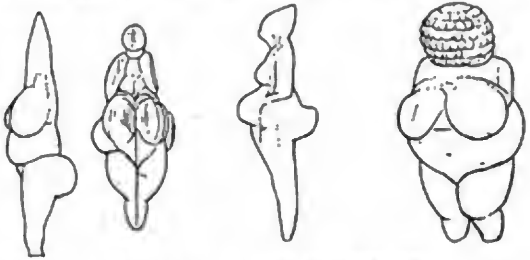


Implements used by Upper Palaeolithic man, including flint arrow heads, points, burins, pins, harpoons, and needles; the engraved reindeer antler at the bottom of the picture is probably an arrow-straightener

men. Finally there is the Magdalenian, named after the rock shelter of La Madeleine, near Tursac in the Dordogne, which brings the story of mankind down to the end of the Old Stone Age, and includes the finest flowering of prehistoric art. We should bear in mind, however, that many local variations of these cultures are recognized, the Aurignacian in particular being divided into three well-differentiated stages; also that, unless implements and fossil bones are found in direct association, it is an exceedingly difficult task to ascribe a given culture to a particular race of men.

For these reasons we must restrict ourselves here to an outline of the general trend rather than involve ourselves in a tedious discussion of the criteria of classification.

All Upper Palaeolithic tools and weapons show a great advance over the Mousterian culture of the more primitive Neanderthal men. They are in general smaller and more finely worked, and are specialized for a much wider range of uses. The typical implement of the early Aurignacian hunters was a flint knife, one side razor sharp, the other blunted and curved over to the point. As time went on, this



Figurines made by Upper Palaeolithic man

was supplemented by a widespread use of bone, antler, and mammoth ivory for the making of polished pins or awls and beautifully fashioned spearheads. Cave walls of the period are decorated with pictures of animals, and sometimes of men, while human figurines have been found near Aurignacian hearths from the Pyrenees to Russia. At some sites skeletons have been discovered with necklaces of perforated shells and animal teeth still in place, while red ochre was widely used for the adornment of the body. Although most of these non-utilitarian practices were probably rooted in magic and superstitition, they nevertheless show the dawn of an artistic sense – all an important landmark in human evolution which will be more fully discussed in the next chapter.

The Solutrean period which followed the Aurignacian was of comparatively short duration, but it saw a great advance in flint technique. Its characteristic implement is the 'laurel leaf' flint – a thin, flat, flaked blade used mainly for spear and arrowheads. The presence of arrowheads shows that the men of this phase had already discovered the secrets of the bow, and the bones of over 100,000 horses at the type site of Solutré give us a clue to their main quarry. Less is known of their art than their material culture, but the Tuc d'Audubert cave in the Pyrenees is famous for its models of clay bison, sometimes ascribed to the Solutrean phase, while there is a decorative frieze of horses, bison, and ibex in the rock shelter of Le Roc, Charente, which is also possibly of this period.

But for the finest flowering of artistic achievement as well as the greatest refinement of material culture so far, we must go to the Magdalenian phase, which began in western Europe some time before 15,000 B.C. This was the last and most splendid episode in the cultural advance of Palaeolithic man, and many of its achievements have not been surpassed down to this day. It is characterized by a great wealth of implements in bone, reindeer antler, and ivory, including needles, harpoons, awls, hammers, and shaft-straighteners, while the record of cave painting and engraving culminates in the mighty polychrome frescos of Lascaux, the supreme artistic achievement of the prehistoric world. Only in the making of flint implements is the Magdalenian phase inferior to some of its predecessors. The Magdalenians tended to neglect flint in favour of bone and other more tractable materials, and the tradition of flint workmanship did not make new advances until Mesolithic times, about 8000 B.C.

The life of the Upper Palaeolithic men, like that of the Neanderthalers, was essentially based on hunting. But the family group had now given place to the tribe, and co-operative effort led to far greater efficiency in the capture of game. In summer the hunters were largely nomadic, pitching their tents of skins near the paths of the migrating herds.

Their life centred on the hearth, an open fireplace surrounded by a circle of stones, the fire serving for cooking and for keeping wild animals at bay by night. If game became scarce it was an easy matter to strike the tents and move to a new area.

In winter life became more static. If the country was open the hunters went to earth in semi-underground dwellings roofed with turfs and skins. If they were near the hills they sought refuge in the rock shelters and caves. Game was scarce in the bleak Ice Age winter, so probably the autumn saw a great drive by the hunters to build up a surplus store of meat. The cold would have preserved the meat for many weeks if it was piled in the open near the caves and protected from scavenging animals by a barricade of thorn bushes. In addition to these reserves the hunters would certainly have made forays after musk ox, reindeer, and mammoth, while there is evidence in the cave paintings that smaller animals may have been caught in traps and snares. If a particularly bad year brought the tribe to the brink of starvation, they may possibly have resorted to cannibalism, although there is no direct evidence of this as in the case of the earlier ape-men of Pekin.

This brief sketch of human life between 10,000 and 30,000 years ago completes our story of the Palaeolithic Age. It also completes the history of man as an animal, for, as we have seen, the Palaeolithic hunters were physically indistinguishable from ourselves, and belonged to the same great species, *Homo sapiens*. The succeeding Mesolithic and Neolithic Ages, which bring us to the dawn of written history, saw no further changes in man's bodily evolution. Yet it would be impossible to bring this book to an end without some discussion of the immense revolution in thought that began in the Palaeolithic Age, and is still continuing in our own times. This revolution has been associated with the dawn in man's consciousness of an awareness of his own nature and problems. It is manifested in the pursuit of knowledge as an end in itself, in the development of artistic sensibility, and perhaps, above all, in the growth of a sense of values. In our final chapter we must examine the origin of these strange mental and spiritual phenomena which have emerged in the final phase of Earth History. They are as much a part of the story as the record of geological and biological change, and there can be no hope of finding a meaning in evolution without taking them into account.

CHAPTER 26

SCIENCE, ART, AND RELIGION

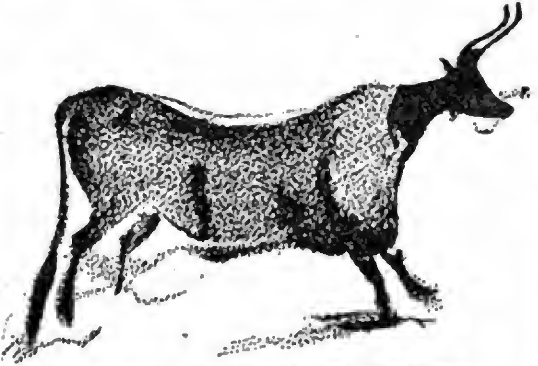
As we have seen in the foregoing chapters, man owes his evolutionary success almost entirely to the precocious development of his brain. As his brain became larger and more complex, his powers of reason increased, and with them the capacity for what is generally termed 'conceptual thought'. This can be defined as the ability to abstract general ideas or concepts from everyday activities and to retain these in memory as principles to be reapplied on future occasions. The powers of conceptual thought not only helped *Homo sapiens* to perform his utilitarian tasks but allowed him to form images of the ends towards which he was labouring. This marked the beginning of an entirely new chapter in evolutionary progress. In evolving man, Nature had produced an organism with a mind that was not only ideally planned to control its flexible and well-adapted body, but was actually able to escape into the realms of abstract thought.

The earliest manifestation of man's powers of conceptual thinking was the extension of the body's possibilities by the characteristically human activity of tool making. An ape may use a stone to crack a nut, but only a man will deliberately fashion an implement to deal with some eventuality not immediately apparent to the senses. Tool making was followed by an increasingly rational approach to the problems of obtaining food and shelter. Man learnt to extend his range of activities and his adaptability to his environment by making a wide range of specialized equipment. He gradually learnt also to harness the forces of Nature for his own ends. For example, the means of controlling fire for warmth and cooking were discovered at least as long ago in human history as the way to make tools. And all these activities showed a growing capacity for abstract thought, an ability to detach the mind from immediate needs and to think rationally about the principles of things.

The activities associated with the growing power and sophistication of the human mind are generally grouped under three main headings – science, art, and religion. In historic times these spheres of thought have tended to become very largely distinct, and often, in fact, hostile to one another. But this has not always been the case, for primitive thought cannot be divided into such clearly differentiated compartments. In discussing the science, art, and religion of the Old Stone Age we should remember that we are only using these terms as convenient labels, for their fields overlapped and merged into one another far more than they do today.

Science in its broadest sense is defined as learning or knowledge. In terms of this definition it can be said to include both art and religion, but we shall here use the word in its more restricted sense – that is, as a means of knowledge of natural or physical phenomena and the immediate principles that govern them. As might be expected, the earliest steps in man's mental evolution were made in this field. The first man to discover the secret of kindling tinder from the frictional heat of a rotating stick was demonstrating a scientific principle. With each repetition of this act he was reapplying the principle to achieve a similar utilitarian end. It is easy to see how in time the idea of the principle as such was abstracted from the series of fire-making acts. Thus man moved from awareness of how certain specific objects behaved to a knowledge of the principle of combustion. And in doing this he had conceived a scientific idea.

A study of recent history suggests that art and religion in their most advanced forms belong to a more sophisticated level of mental development than science, but they too had a utilitarian origin. We have told how the men of the Old Stone Age made engravings and paintings on the walls of their caves and fashioned models of animals from clay. At Altamira in Spain, for example, the roofs and walls of the caves are covered with magnificent polychrome frescos of



A red cow with a black head from the Lascaux caves

A bison from the Altamira caves

bison, horses, red deer, and wild boar, while at Lascaux, near Montignac in France, there is a huge rhinoceros and many finely executed paintings of horses and giant black bulls. These splendid works of art were once regarded as evidence that prehistoric man had a highly developed aesthetic sense, and spent his leisure hours decorating his cave walls for the pleasure of himself and his family. More recently, however, this view has had to be abandoned, for many of the paintings are found in chambers deep in the hillsides, which could not possibly have been used for living quarters. Also, in some caves, the paintings have been placed one on top of another without any apparent reason, and it is difficult to believe that this would have been done if the main object had been the pleasure of the beholder.

The explanation of these pictures now generally accepted is that they formed part of the rituals of sympathetic magic. This is the activity, common among primitive hunting races even today, of identifying animals of the chase with their visual representations. Before going to the hunt prehistoric man probably held a ceremony in some allegedly sacred spot deep in the caves, where magic spells were woven round the images of mammoth, bison, or reindeer. Spears were thrown at the painted symbol in the hopes that this would give the hunters the magic power to strike down the living creature. A form of this magic idea survived as recently as the last century in England, when simple country folk still believed that pins stuck into the wax effigy of an enemy would bring him bad luck, or even death.

Despite this magical aspect of the first art there is apparent in many prehistoric paintings a strong sense of formal beauty, which foreshadows the great artistic achievements of later ages when the aesthetic impulse had transcended its materialistic origins. It is even possible that some of the pictures in the open rock shelters, as opposed to those painted deep in the caves, had a purely decorative intent. And there can be little doubt that some of the carvings done on the handles of bone and ivory implements were placed there to satisfy a disinterested creative urge.

From art we move to religion, which in its purest form is the most abstract, and also the most highly evolved, attempt at knowledge so far made by the human mind. This, too, had utilitarian beginnings, but, like art, it transcended its original function as man gradually achieved a higher degree of mental evolution. The main impulse behind the formation of the earliest religious beliefs was probably fear. Once the immediate problems of survival had been solved, prehistoric man began to reflect on his own nature and the meaning of his life. In this he differed from his animal forebears, whose mental limitations caused them to live for the day or the hour, with no other pre-occupation than the source of the next meal and the pleasures or excitements of play, sex, or a languorous siesta in the summer sunshine. Man was oppressed by his loneliness and his apparent insignificance in a cold and hostile Universe. The forces of Nature filled him with awe and apprehension. And as a frightened child seeks comfort from those omnipotent beings, its parents, he turned to gods made in his own image, or in the image of the natural powers that seemed to control his life.

There was also a sound biological reason behind the religious beliefs of primitive man. Survival in a world moving from domination by brawn to domination by brain demanded a growing emphasis on co-operative effort. This shift in emphasis required the discipline of law. And the taboos associated with primitive religion, however naïve and irrational they may seem to us now, were the beginnings of a legal code aimed at the survival of the species.

Naturally enough the first religious beliefs, and therefore the first laws, found their sanction in the wisdom and experience of the oldest members of the tribe. Veneration of the Old Man, and of the spirits of the tribal ancestors, was therefore a common factor in primitive thought. The leader of the tribe, elderly, bearded, and a living testimony to the survival value of his own attitude to life, was generally accepted by those with more limited experience as a symbol of wisdom and power. Primitive religion shows unmistakable evidence of this patriarchal influence on the human mind, and the anthropomorphic element persists even in more highly evolved creeds. For instance, no fair-minded Christian can fail to recognize survivals of primitive religious thought in the Jehovah of the Old Testament; stern, jealous, didactic, quick to anger and ruthless in punishment, he retained many of the savage characteristics of a tribal god. It was not until nearly 2,000 years ago that western religion was emancipated from fear of this formidable being and evolved a philosophy of compassion and tenderness.

But even for the most unsophisticated minds the Old Man was not a complete and sufficient answer to the problems that came with self-awareness. The forces of nature, which played such an important part in the life of early man and still do in the life of primitive communities, remained beyond the control of purely human minds. The Old Man or his deputy, the witch doctor, might be regarded as the representatives of the tribe to intercede with these forces, but the forces themselves still retained a terrifying independence. Thus they too became regarded as gods, to be thanked or placated by mortification and sacrifice. There was a sun god, and a rain god, and a god or goddess of the earth and the sea, each of whom played a vital role in the beliefs and activities of primitive men.

The belief in the Old Man and in the diverse natural gods who were reputed to control the workings of the external world survived even after the growth of civilization. In pagan systems the natural forces were themselves all-powerful and the gods personifying them were directly worshipped. In monotheistic creeds faith was pinned on an idealization of one individual, who had magical powers to intercede with every hostile force that might threaten the well-being of the group. The witch doctor, the prophet, the religious leader, all played a vital role in the infinite variety of systems that sought to reconcile man to his loneliness in a hostile, or at best, an impersonal Universe. From these humble beginnings stemmed the whole fabric of modern philosophical and religious thought, which is still struggling, although we may hope with increasing assurance, to answer those fundamental questions concerning the significance of the Universe and human life which already preoccupied our Ice Age Ancestors.

This book does not aim to present a personal view of Earth history but, to conclude, it does seem necessary to make a few observations on the way human thought has evolved since the end of the Old Stone Age. Science, art, and religion arose, as we have just seen, as part of man's evolutionary progress towards self-awareness. They were attempts to increase his knowledge of the Universe, or to release him from the fear that accompanied that knowledge; and although each had its own paraphernalia of magic and superstition, they formed part of a single mental process. We have already said that with the passing of the centuries these three activities, which began in a common instinct of wonder, tended increasingly to diverge. A time was soon reached when their respective attitudes to life became quite incompatible, and they ceased almost entirely to interact.

Thus technicians and scientists concentrated on the understanding and control of natural forces, and evolved ever more efficient and powerful machines. Religious leaders told how through humility and faith a supernatural Being would comfort the sorrowful and provide a solution to the problems of a distracted world. Artists sought to utilize line or colour, words or musical notes, as symbols to express a mystical significance in things that was denied to the unaided human understanding. But only a handful of men since the dawn of human history have sought to combine the reports from these different activities to produce an overall picture of what we know of the Universe and ourselves.

No student of Earth history can regard this divergence of the means of knowledge without alarm. A certain amount of specialization is desirable on the mental as on the physical plane of existence, but evolution has given some awful warnings of what can happen when specialization begins to run away with itself. In the predominantly physical phase of evolution, before the appearance of *Homo sapiens*, the degree of specialization was beyond the control of the organism exhibiting it. But fortunately with man this is not the case. The human consciousness is now sufficiently developed to grasp the implications of its own acts, and evolution can, within certain limits be deliberately controlled. If man is to avoid the pitfalls that brought about the downfall of his predecessors, it seems certain that a higher synthesis must be achieved between the different departments of thought.

The whole record of Earth history teaches us that evolution is moving steadily towards greater awareness, and it is surely desirable that every available technique of knowledge should co-operate to further this process. Science, it is obvious, can give no complete or convincing account of a Universe which contains non-material qualities – beauty, for example, or goodness, or mind itself. The investigation of these phenomena is the province of art and religion. But it is also important to realize that both art and religion must take account of the views of science if they are to achieve the complete knowledge at which they aim. Religion especially, as its wiser leaders readily admit, is not yet completely emancipated from the bondage of dogma and prejudice, and until it can make a closer *rapprochement* with scientific thought there is little hope that a more accurate view of the Universe and its meaning will be achieved.

To sum up: science, art, and religion, evolving to new insight from their starting place in the mind of primitive man, are inseparable processes. They are all techniques of knowledge operating with equal validity at different levels of awareness. Science tries to answer the questions 'what?' and 'how?', art and religion the question 'why?'. Unless a new synthesis can be achieved between them the human race may be extinguished with the same tragic finality as the dinosaurs before them, without ever having perceived the true nature and significance of the Universe, of life, and of evolution itself.

This brief description of the pattern of human thought, and the evolutionary *impasse* into which it may now be leading us, brings us to the end of our Guide to Earth History. With the close of the Pleistocene Epoch 10,000 years ago man was already setting out on the road to civilization. From being a hunter and food gatherer, living like a superior ape on the providence of the land, he was slowly learning the art of growing crops and domesticating animals. After many centuries of experiment he founded in Egypt and Mesopotamia the first great settled human communities in the history of the Earth. His story thereafter became a well-documented record of personalities and events – a story that is the fascinating climax of the great evolutionary processes which have manifested themselves through the 3,000 million years of Earth history.

The meaning of these processes we can only guess at, and our long journey must end, as it began, in wonder. And not wonder only, but humility, for no one can contemplate the majestic workings of the Universe without a profound sense of his own insignificance. Yet we who are numbered among the survivors of this mysterious record of growth and change can at least comfort ourselves with one reflection. Means of knowledge are open to us which were denied to every one of our less fortunate predecessors in the long procession of life, and these have at last given us some measure of control over our environment and our destiny. It is our responsibility as well as our privilege to see that they are wisely used.

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